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NATURAL PHILOSOPHY.

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FIRST BOOK
OF
NATURAL PHILOSOPHY;

INCLUDING PROPERTIES OF BODIES—MECHANICS—HYDROSTATICS—
HYDRAULICS—PNEUMATICS AND ACOUSTICS:

WITH QUESTIONS ON EACH PAGE, AND A DICTIONARY OF TERMS.

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ADVERTISEMENT.

THE present treatise consists of six chapters condensed from the Authors' Manual of Natural Philosophy, with a Dictionary of Terms selected from the same work. It is presented by the publisher as the second of a series of elementary Text-Books, intended to be published by him, on those branches of science which, it is presumed, may be advantageously introduced into schools, as preparatory to a more finished education, and for students intended for the learned professions.

BIBLIOTHECA·BODLEIANA

CONTENTS.

CHAP. I.—PROPERTIES OF BODIES.

Page
Properties of bodies, ... 1
Extension, ... 1
Figure, ... 2
Impenetrability, ... 2
Divisibility, ... 3
Inertia, ... 3
Indestructibility, ... 4
Attraction, ... 5
„ of cohesion, ... 5
„ of gravitation . . . 6
„ capillary, ... 7
„ chemical, ... 8
Density and rarity, ... 9
Hardness and elasticity, . . 10
Brittleness, ... 10
Malleability, ... 11
Page
Ductility, ... 11
Tenacity, ... 12
Terrestrial gravitation, . . . 12
Velocity of falling bodies, . . 14
Attraction proportionate to the matter, ... 15
Laws of motion, ... 16
Velocity of motion, . . . 17
Force, or momentum of moving bodies, ... 18
Action and reaction, ... 18
Reflected motion, ... 19
Centre of gravity, ... 22
Equilibrium, ... 25
Curvilinear motion, ... 25
Pendulum, ... 29

CHAP. II.—MECHANICS.

Mechanics, definitions in, . . . 31
Lever, first kind, ... 31
„ second kind, ... 35
„ third kind, ... 36
Wheel and axle, ... 38
Pulley, ... 43
System of pulleys, ... 45
Inclined plane, ... 47
Wedge, ... 50
Screw, ... 51
„ perpetual, ... 53
Mechanical powers resolved into three, ... 54
Uses of machinery, . . . 54

CHAP. III.—HYDROSTATICS.

Elastic and inelastic fluids, . . 55
Equal pressure of water, . . . 56
Hydrostatic press, ... 59
Water level, ... 61
Spirit level, ... 62
Specific gravity, ... 62
Syphon, ... 63
Intermitting springs, ... 64

CHAP. IV.—HYDRAULICS.

Object of hydraulics, ... 66
Friction between solids and fluids, . 68
Archimedes's screw, ... 70
Water raised by ropes, . . . 71

CHAP. V.—PNEUMATICS.

Object of Pneumatics, . . . 72
Elasticity of air, ... 72
Pressure of the atmosphere, . . 74
Air-pump, ... 75
Experiments with air-pump, . 78
Condenser, ... 79
Pressure of the atmosphere on liquids, 80
Barometer, ... 82
„ wheel, ... 84
„ uses of, ... 85
Water pumps, ... 87
Fire engine, ... 91
Hiero's fountain, ... 92

CHAP. VI.—ACOUSTICS.

Undulations, ... 92
Object of acoustics, ... 94
Echo, ... 99
Musical sounds, ... 103
Æolian harp, ... 104
Scale of musical notes, . . . 10
Wind, or atmospheric currents, .

INDEX.

Acoustics, 92
Action and reaction, 18
Æolian harp, 104
Air, elasticity of, 72
Air-gun, 79
Air-pump, 75
Angle of incidence, 20
    of reflection, 21
Annealing, 11
Archimedes's screw, 70
Atmosphere, elasticity of, 72
    pressure of, 74, 80
Atmospheric currents, 109
Atoms, 1
Attraction, 5
    of cohesion, 5
    of gravitation, 6
    capillary, 7
    chemical, 8
Axis of motion, 22
Axle and wheel, 38
Balance, 33
Barometer, 82
    wheel, 84
    uses of, 85
Bent motion, 25
Bodies, properties of, 1
Bramah's hydrostatic press, 59
Brittleness, 10
Capillary attraction, 7
Capstan, 40
Centre of gravity, 22
    of motion, 22
Centrifugal force, 21
Centripetal force, 21
Chemical attraction, 8
Chladni's experiments, 98
Chromatic scale, 108
Condenser, 79
Curvilinear motion, 25
Density and rarity, 9
Destructive distillation, 4
Diatonic scale, 106
Dilatation and expansion, 10
Divisibility, 3
Ductility, 11
Echo, 99
Elasticity, 10
    of water, 56
    of air, 72
Equilibrium, 25
Expansion, 10
Extension, 1
Falling bodies, 14
Figure, 2
Fire engine, 91
Fluids, 55
Fluids, elastic and inelastic, 55
    pressure of, 56
Force, 16, 18, 31
    centrifugal and centripetal, 21
    not created, 42
Fountain of Hiero, 92
Friction between solids and fluids, 68
Fulcrum, 31
Gamut, 106
Gaseous bodies, 72
Globular form, 5
Gold leaf, thickness of, 11
Gravitation, terrestrial, 12
Gravity, force of, 12
    centre of, 22
    specific, 62
Hardness and elasticity, 10
Hiero's fountain, 92
Hydraulics, 66
Hydrostatic press, 59
Hydrostatics, 55
Impenetrability, 2
Incidence, angle of, 20
Inclined plane, 47
Indestructibility, 4
Inertia, 3
Intermitting springs, 64
Level, water, 61
    spirit, 62
Lever, 31
    perpetual, 39
Machines, 31
Malleability, 11
Matter, 1
    inertia of, 3
Mechanical powers, 31
    resolvable into three, 54
Mechanics, 31
    definitions in, 31
Molecules, 1
Momentum, 18
Motion, defined, 16
    laws of, 16
    velocity of, 17
    reflected, 19
    circular, 21
    curvilinear, 25
    centre of, 22
    axis of, 22
Musical instruments, 103
Musk, scent of, 3
Octave, 106
Oscillations, 92
Pendulum, 29
    isochronous, 30
Philosophy, natural, 1
Plane, inclined, 47
Pneumatics, 72
Power, 31
Properties of bodies, 1
Prying and lifting, 35
Pulleys, 43
    system of, 45
Pumps, water, 87
    common, 87
    lifting, 88
    forcing, 89
    chain, 90
Rarity, 9
Reaction, 18
Reflected motion, 19
Reflection, angle of, 21
Rest, 17
Scale of musical notes, 106
    diatonic, 106
    chromatic, 108
Screw, 51
    perpetual, 53
    Archimedes's, 70
Size, 2
Sound, 94
    conduction of, 94
    velocity of, 96
    musical, 103
Specific gravity, 62
Spirit level, 62
Springs, intermitting, 64
Steel yard, 34
Suction, 80
Syphon, 63
Tenacity, 12
Terrestrial gravitation, 12
Trade winds, 110
Triad, 108
Undulations, 92
Use of machinery, 54
Vapours, 56
Velocity of falling bodies, 14
    of motion, 17
Vibrations, 92
Volume, 2
Water, elasticity of, 56
    equal pressure of, 56
    bursting power of, 58
    raised by ropes, 71
Water level, 61
Wedge, 50
Weight of bodies, 7, 12, 31
Welding, 11
Wheel and axle, 38
Wheel barometer, 84
Wheels, system of, 41
Whispering gallery 102
Windlass 40

FIRST BOOK OF NATURAL PHILOSOPHY.

CHAP. I.

THE PROPERTIES OF BODIES.

1. NATURAL PHILOSOPHY is a comprehensive term, including all those branches of physical science which treat of matter, its properties, and its motions. *Matter* is the general designation of all substances possessing weight, as distinguished from light, heat, and electricity, which, being destitute of appreciable weight, are commonly termed "imponderable agents." It is possible to conceive that a portion of matter, as a grain of sand, may be divided into a million parts, and each of these into a million more, and so on *ad infinitum.* It may, however, be true that a grain of sand cannot be divided into more than a certain number of parts, each of which possesses such cohesive power as to resist further division. These ultimate particles are called *atoms* or *molecules*, and it is by aggregation of these particles into a definite size and shape, that a *body* is constituted.

2. *Extension.*—Extension is the property which bodies possess of occupying space, and relates to the qualities of length, breadth, and thickness, without which no substance can exist. Extension has no respect to the size or shape of a body. A block of wood, of the dimensions of a square foot, may be divided into numerous smaller blocks, exactly resembling the large one in shape; these may again be divided, until each block be reduced to the hundredth part of an inch in diameter; and each of these may be further subdivided, until they defy our power of measuring them; yet it is obvious that each little block will possess length, breadth,

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1. What is the subject of Natural Philosophy? What is meant by matter? What is an atom or molecule? How is a body constituted? —2. What is extension, and to what qualities of matter does it relate? Show that it has no relation to size or shape. What is the common designation of this property?

and thickness; in other words, each will possess the property of *extension* as really as the original block, the only difference being that of dimension. It is, in fact, impossible to form a conception of matter, however minute the particle, without connecting with it the idea of its having a certain bulk, or filling a certain extent of space. This property of bodies is termed, in common language, *size* or *volume.*

3. *Figure.*—Figure or form is the result of extension, for we cannot conceive that a body has length, breadth, and thickness, without its having some kind of figure, however irregular. Some solid bodies are found naturally under determinate forms, from which they never vary: a crystal of quartz has six sides, a garnet twelve sides. Other solids are so irregular, that they cannot be compared with any mathematical figure, as a fragment of a rock, or a chip of wood. Fluid bodies have no determinate form, but take their shapes from the vessels in which they are contained. The *volume* of a body has no relation to its figure: bodies which have the same figures may possess very different volumes; and bodies may have the same volume, under very different figures; thus, two masses of matter may present the same volume, although the one be round and the other square.

4. *Impenetrability.*—Impenetrability is the property by which one body occupies a certain space, to the exclusion of every other body from that space; or, in other words, by which two bodies cannot occupy the same space at the same time. 1. A nail, driven into a board or piece of lead, does not penetrate the wood or the metal; it merely *separates* and *displaces* the particles of these substances. 2. If a vessel be filled with water, and a stone, or any other substance heavier than water, be dropped into it, a quantity of the water, precisely equal to the bulk of the heavy body, will be displaced and flow over, affording a decisive proof that a body cannot enter the space occupied by another body, without previously ejecting the latter. 3. Lastly, if a vessel be inverted in water or any other liquid, the impenetrability of the air prevents the ascent of the liquid within the vessel. This property of

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3. What connection exists between extension and figure? What kind of bodies exhibit regularity of figure? Show that the volume of a body has no necessary relation to its figure.—4. What is meant by impenetrability? *What effect is really produced, on driving a nail into a piece of wood? State some other cases in proof of the impenetrability of matter. How is this property turned to account in the use of the diving-bell?*

matter has been usefully and ingeniously applied in the construction and uses of the diving-bell.

5. *Divisibility.*—Divisibility is the property by which a body may be divided into minute parts. The division of matter, by mechanical means, is subject to limitation, but the extent to which it may be practically carried, almost exceeds credibility. 1. One grain of colouring matter will impart a tint to five pounds of pure water; and, as it is possible to render visible so small a quantity of water as a thousandth part of a grain, this minute portion of the mixture must contain a thirty-five millionth part of the grain of colouring matter. 2. A single grain of musk will diffuse a powerful odour through a spacious room, without losing any appreciable portion of its weight; the odour depends on the incessant radiation of particles of the musk, and the process will continue in activity for several years. 3. A grain of gold may be hammered so thin as to cover fifty square inches of surface, and present two millions of visible points; and the gold which covers the silver wire, employed in making gold lace, is spread over a surface twelve times as great. Wollaston made a gold wire of such extreme tenuity, that an ounce of it would extend fifty miles. 4. The film of soap and water, which constitutes the thinnest part of the soap-bubble, does not exceed in thickness the 2,500,000th part of an inch. 5. Lastly, the researches of Biot have shewn, that the thread by which the spider suspends herself from the web, is composed of more than 6000 single threads.

6. *Inertia.*—Inertia is the property by which matter is incapable of putting itself in motion, or of arresting its own progress, when put in motion by some force. A ball rolled on the ground soon ceases to move, owing to the impediments it meets with from the roughness of the surface; if rolled on ice with the same force, its motion continues for a much longer period, the impediments being fewer; if projected into

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5. What is divisibility? Illustrate this property by examples taken from unorganized, and from organized matter.—6. What is meant by inertia? Why will a ball roll farther on ice than on the ground? Why, with the same force of projection, will the ball move further in air than on ice? What would result from projecting the ball into free space? What are the causes which resist the perpetual motion of bodies? Why is a passenger standing in a carriage thrown backward, when the carriage is suddenly put in motion? Why is he thrown forward, whe the carriage is suddenly stopped?

the air, its motion is arrested by gravity; but if projected into free space, where no impediments occur from air, friction, or gravity, it would exhibit the phenomenon of perpetual motion. Familiar instances of inertia are found in the employment of *locomotion*. A considerable force is required at first to set a carriage in motion; but when this has been effected, it moves onward with comparative ease, so that, in fact, a considerable force becomes necessary to arrest its progress. If a passenger be standing in a carriage when suddenly put in motion, his feet, obeying the impulsion of the carriage, are drawn forward; his body, obeying the law of inertia, remains in its former position; he, consequently, falls *backward*. On the other hand, if the passenger be standing when the carriage is suddenly stopped, the opposite result will take place: his body has acquired an onward motion, imparted to it by that of the carriage, and the sudden stoppage of the latter throws him *forward*.

7. *Indestructibility.*—Indestructibility is the property by which matter never ceases to exist. It may change its form, and disappear, but it is not annihilated. 1. Mercury, water, and other substances, may be converted into vapour, or distilled in close vessels, but they may be again condensed by the application of a cold body, and restored to their former condition, without the loss of a single particle. 2. Animals and vegetables die, and are decomposed, but their elementary particles immediately enter into new combinations, and furnish materials of nutriment for other animals and vegetables. 3. In the following case of what is called, in the language of chemists, *destructive* distillation, it is evident that *nothing is destroyed*. When a piece of wood is heated in a close vessel, as a retort, we obtain water, an acid, several kinds of gas, and a black, porous substance, called charcoal. The wood is thus decomposed, and its particles take a new arrangement, and assume new forms; but that nothing is lost, is proved by the fact, that, if the water, acid, gases, and charcoal, be collected and weighed, they will be found exactly as heavy as the wood was before distillation.

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7. What is meant by indestructibility? How may a liquid, which has been reduced to vapour, be restored to its former condition? When *animal or vegetable bodies* undergo decay, what becomes of their constituent *particles? Is there any ground* for believing that matter is, *under any circumstances*, annihilated? Describe the process of what is *called destructive distillation*, and show that nothing is thereby destroyed.

8. *Attraction.*—Attraction is the property by which bodies tend towards each other. This property manifests itself in various ways, and has received specific designations according to the circumstances under which it acts. The following are the several kinds of attraction:—

9. *Attraction of cohesion.*—Every *particle* of matter has a tendency to approach and unite itself to other *particles*. This kind of attraction operates at insensible distances, and consists in maintaining the constituent parts of a body in cohesion with each other, and in resisting their separation. The attraction of cohesion, as it occurs in *solid* bodies, may be exemplified by the difficulty experienced in separating two substances with smooth surfaces, which have been pressed closely together. If two pieces of clean plate glass, or two disks of lead or brass, be brought into close union by a screw-like pressure, a considerable force will be required to separate them from each other; the effect will be much increased by interposing a little oil between the surfaces, in order to fill up any superficial inequalities.

10. "When the particles of *fluid* substances are left to arrange themselves according to the laws of attraction, the bodies which they compose assume the form of a *globe* or ball. Drops of water thrown on an oiled surface or on wax, globules of mercury, hailstones, a drop of water adhering to the end of the finger, tears running down the cheeks, and dew drops on the leaves of plants, are all examples of this law of attraction. The manufacture of shot is also a striking illustration of this law: the lead is melted and poured into a sieve, at the height of about two hundred feet from the ground; the stream of lead, immediately after leaving the sieve, separates into round globules, which, before they reach the ground, are cooled and become solid, and thus are formed the shot used by sportsmen.

11. "To account for the *globular* form in all these cases, we have only to consider that the particles of matter are mutually attracted towards a common centre, and in liquids, being free to move, they arrange themselves accordingly.

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8. What is meant by attraction?—9. How does the attraction of cohesion operate? Give instances of cohesive attraction in solid bodies.—10. What forms do fluids take when their particles are left to their own arrangement? Give examples of this law.—11. How is the globular form which liquids assume accounted for? If the particles of a body are free to move, and are equally attracted towards the centre, what must be its figure?

In all figures, except the globe or ball, some of the particles must be nearer the centre than others. But in a body that is perfectly round, every part of the outside is exactly at the same distance from the centre. Thus, the corners of a cube, or square, are at much greater distances from the centre, than the sides, while the circumference of a circle or ball is everywhere at the same distance from it. This difference is shown by Fig. 1, and it is quite obvious, that if the particles of matter are equally attracted towards the common centre, and are free to arrange themselves, no other figure could possibly be formed, since then every part of the outside is equally attracted. The sun, earth, moon, and indeed all the heavenly bodies are illustrations of this law."

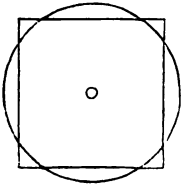
Fig. 1.

12. *Attraction of gravitation.*—As the attraction of cohesion is the force by which the particles of a body are united into masses, so the attraction of gravitation is the force by which these *masses tend toward each other;* and as the former law operates at *sensible,* so the latter operates at *insensible* distances. The term gravitation does not here strictly refer to the weight of bodies, but to the attraction of the masses of matter towards each other, whether downwards, upwards, or horizontally.* The attraction of gravitation is mutual, since all bodies not only attract other bodies, but are themselves attracted. 1. The sun attracts the earth at a distance of 95,000,000 miles; the earth attracts the moon at the distance of 240,000 miles; the moon reciprocally attracts the earth, the moveable parts of which, or the waters, under the influence of this attraction, exhibit the phenomena of tides. Upon this principle, Newton founded his law of universal gravitation. 2. Two cannon balls, when suspended by long cords, so as to hang very near each other, are found

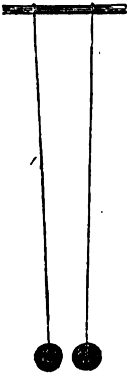
Fig. 2.

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12. What is meant by attraction of gravitation? Can one body at- *tract another without being* itself attracted? How is it proved that *bodies attract each other?*

to exert a mutual attraction, so that neither of the cords is exactly perpendicular, but each approaches the other, as represented in the preceding figure. 3. In the same manner, the heavenly bodies, when they approach each other, are drawn out of the line of their paths, or orbits, by mutual attraction. 4. Lastly, the effect of gravitation, as it exists on the surface of our globe, is seen in the tendency which all bodies possess of descending in straight lines toward the centre of the earth; and the force which acts in separating a body from the surface of the earth, or in preventing it from descending to the surface, is called its *weight*.

13. "The force of attraction *increases* in proportion as bodies approach each other, and by the same law it *diminishes* in proportion as they recede from each other. Attraction, in technical language, is *inversely as the squares of the distances between the two bodies:* that is, in proportion as the square of the distance increases, in the same proportion attraction decreases. Thus, if at the distance of 2 feet, the attraction be equal to 4 pounds, at the distance of 4 feet, it will be only 1 pound; for the square of 2 is 4, and the square of 4 is 16, which is 4 times the square of 2. On the contrary, if the attraction at the distance of 6 feet be 3 pounds, at the distance of 2 feet it will be 9 times as much, or 27 pounds, because 36, the square of 6, is equal to 9 times 4, the square of 2. The force of the attraction of gravitation, is in proportion to the quantity of matter the attracting body contains. Some bodies of the same bulk contain a much greater quantity of matter than others: thus, a piece of lead contains about twelve times as much matter as a piece of cork of the same dimensions, and therefore a piece of lead of any given size, and a piece of cork twelve times as large, will attract each other equally.

14. *Capillary attraction.*—"Capillary attraction is the force by which a liquid rises in small tubes, or porous substances, above its level. If a small glass tube be placed in water, the water on the *inside* will be raised above the level of that on

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13. By what law, or rule, does the force of attraction increase? By what rule does it decrease? Do bodies attract in proportion to bulk, or quantity of matter? What would be the difference of attraction between a cubic inch of lead and a cubic inch of cork? Why would there be so much difference?—14. What is meant by capillary attraction? How is this kind of attraction illustrated with a glass tube? Give some common illustrations of this principle.

the *outside* of the tube. A great variety of porous substances are capable of this kind of attraction. If a piece of sponge or a lump of sugar be so placed, that its lowest portion touches the water, the fluid will rise and diffuse itself through the whole mass. In the same manner, the wick of a lamp will carry up the oil to supply the flame, though the flame is several inches above the level of the oil. If the end of a towel happen to be left in a basin of water, it will empty the basin of its contents. And on the same principle, when a dry wedge of wood is driven into the crevice of a rock, and afterwards moistened with water, as when the rain falls upon it, it will absorb the water, swell, and sometimes split the rock. In Germany, millstone quarries are worked in this manner." Lastly, it is supposed that this kind of attraction is one of the causes of springs of water in the earth. The water rises through porous beds of sand, small stones, and crevices of rocks, and thus reaches surfaces of great elevation. The lower parts of the walls, and the earthen floors of cottages, are rendered constantly damp by the attraction of moisture upwards from the ground; hence the necessity of removing all *porous* matters from the foundations of houses.

15. *Chemical attraction.*—The forces of attraction, already described, are among the *physical* properties of matter. There are, however, other forces in nature, which belong more exclusively to the science of chemistry, and which, with reference to the materials of which our globe is composed, produce effects equal in importance and interest to any other. 1. If water be mixed with water, or salt with salt, the effect is merely an increase of *quantity;* no change of *quality* is produced. 2. If a blue and a yellow powder be mixed together, a green powder is produced; but this is merely an effect impressed upon the eye by the intimate *mixture* of the yellow and blue light which is separately reflected from the minute particles of each; these particles may be separated mechanically, and the powders restored to their former appearance. 3. If two coloured liquids, having no chemical attraction for each other, be mixed together, a liquid of a different colour is produced, and the two ingredients cannot, it is true, be mechanically separated; yet, even in this case, the liquid is a mere *mixture*, and its properties are accordingly intermediate

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15. Explain, generally, **the difference between a mechanical mixture** *and a chemical compound.*

between those of the liquids mixed. In these three cases there is no *change of property*, nor is any new property superadded; in other words, the substances being similar, no chemical attraction takes place. 4. But when potash, dissolved in water, is mixed with tartaric acid, also dissolved in water, a solid substance, called cream of tartar, is thrown down in the vessel; this substance is neither potash nor tartaric acid, nor can either of these ingredients be again procured from it; the liquid also from which it subsided, no longer presents the qualities of the ingredients which were mixed in it, but those of a *new* and entirely *different* substance. The potash and tartaric acid have, therefore, united with each other, to form a *chemical compound*, which, when carefully collected, is exactly of the same weight as the ingredients possessed before their union, but of entirely different qualities. This compound is formed by chemical attraction.

16. In addition to the universal properties of matter above described, there are several other qualities, which are peculiar to certain bodies, and in different degrees; or peculiar to some bodies, without affecting others in the slightest degree. These are density and rarity; hardness and elasticity; brittleness, malleability, ductility, and tenacity.

17. *Density and rarity.*—The quality of density relates to the *compactness* of bodies, or the number of particles which a body contains within a given bulk; in other words, it denotes closeness of texture. Bodies, which are most dense, are those which contain the least number of pores. Hence the most dense substances in nature are found among the metals; gold, for instance, is upwards of 19 times, and platinum nearly 21 times, heavier than an equal bulk of water. But density is not an essential character of metals: potassium and sodium are so light as to float upon the surface of water. Two bodies being of the same bulk, that which weighs more than the other, is the more dense. Some metals become denser on being hammered, their particles being brought together permanently by this operation. The density of air is increased by forcing more into a close vessel than it naturally contains. *Rarity* is the quality opposed to density, and

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16. Enumerate the peculiar qualities of bodies.—17. What is density? What bodies are most dense? Show that density is not an essential quality of metals. How may this quality be increased in metals? What is rarity? To what class of bodies is the term generally applied?

denotes that the substance to which it is applied is porous and light: the intervals between the particles of matter are augmented, and hence the same number of particles occupy a larger space. The term is chiefly applied to aeriform bodies, the terms *dilatation* and *expansion* being employed in speaking of solids and liquids.

18. *Hardness and elasticity.*—The quality of hardness is not in proportion, as might be expected, to the density of the substance, but to the force with which the particles of a body cohere, or keep their places. Glass, for instance, will scratch gold or platinum, though these metals are much more dense than glass. It is probable, therefore, that these metals contain the greatest number of particles, but that those of glass are more firmly fixed in their places. *Elasticity* is the quality by which bodies, after being forcibly compressed or bent, regain their original state when the force is removed. Some substances are highly elastic, while in others this quality is entirely absent. The separation of two bodies, after collision, is a proof that one or both are elastic. The quality of elasticity is connected with that of hardness, the hardest bodies being also the most elastic. Ivory, glass, marble, flint, and ice, are elastic solids: an ivory ball dropped upon a marble slab, will bound to a height nearly equal to that from which it fell, and no mark will be left on either substance.

19. *Brittleness.*—This quality denotes that the bodies to which it belongs admit of being easily broken, or separated into irregular fragments; and it is found chiefly in hard bodies. It does not appear that brittleness is entirely opposed to elasticity, since, in many substances, these qualities are united, Glass is the standard or type of brittleness, and yet a ball, or fine threads of this substance, are highly elastic, as may be seen by the bounding of the one, and the springing of the other. Brittleness often results from the treatment to which substances are submitted. Iron, steel, brass, and copper, become brittle when heated and suddenly cooled; but, if cooled slowly, they do not admit of being easily broken.

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18. Is the quality of hardness proportional to the density of a body? Why will glass scratch gold or platinum? Which are the hardest metals? What is meant by elasticity? How is it known that bodies possess this *property? Mention several* **elastic solids.—19. What is brittleness?** *Give an instance in which the* **qualities of brittleness and elasticity are** *united. How may iron, steel,* **and brass be rendered brittle?**

20. *Malleability.*—Malleability is the quality by which some metals admit of being extended into thin plates or leaves under the hammer, or rolling-press; its employment is of great importance in the arts and conveniences of life. This quality depends upon a high degree of *tenacity* connected with a certain degree of *softness.* The malleable metals are gold, silver, iron, copper, and some others. Of these, gold is the most malleable: a grain of gold may be extended so as to cover 50 square inches of surface, and to have a thickness not exceeding 1-282,020th of an inch; it may thus present two millions of visible points, and admit of the transmission of light through its substance. Metals which have become brittle, either in consequence of fusion, or of long continued hammering, are again rendered malleable by *annealing*, or the process of heating a metallic body, and allowing it to cool in a moderate temperature. A few of the malleable metals can be *welded*, or portions of them joined together by hammering. Iron and platinum may be welded together at a bright-red heat, and fragments of potassium may be made to adhere by pressing them together by the hand at the ordinary temperature of the air.

21. *Ductility.*—Ductility is the quality by which a metal admits of being drawn out into wire. Wollaston succeeded in drawing platinum into threads not much larger than those of the spider's web; he also formed a gold wire so thin as to be only 1-5000th of an inch in diameter: 550 feet of it weighed only one grain; an ounce of it would extend 50 miles. We might expect that the most malleable metals would be also the most ductile; but experiment proves that this is not the case. The ductility of metals is not always proportional to their malleability; iron, for instance, may be drawn into very fine wire, but it cannot be beaten into very thin leaves; on the other hand, tin and lead may be hammered into thin leaves, but cannot be drawn into small wire.

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20. What is meant by malleability? Upon what other qualities does this quality depend? Which are the malleable metals? Illustrate the malleability of gold. How may metals which have become brittle, be rendered malleable? What is meant by welding?—21. What is meant by ductility? To what extent has the ductility of gold been carried? Are the most malleable metals also the most ductile? Give an instance in proof of the contrary.

22. *Tenacity.*—Tenacity is the quality by which a body resists extension or the separation of its parts; it is a direct result of the attractive force of cohesion among the particles of a solid, and may be employed as a measure of the intensity of this form of attraction. There is a considerable difference in the tenacity of different substances; some possess this quality in a remarkable degree, while others are torn asunder by the smallest force. 1. Every thing prepared from flax and hemp, is composed of woody tissue, which possesses great tenacity and strength, and is hence employed in the manufacture of linen; whilst cotton is composed of cellular tissue, which is brittle, and possesses little or no cohesion among its particles. 2. The tenacity of different metals is determined by ascertaining the weight which a wire of a certain thickness can support without breaking. This quality appears to be highest in iron, and lowest in lead.

PHENOMENA OF GRAVITATION.

23. *Terrestrial gravitation.*—It has already been stated, § 12, that the force by which bodies, in masses, are drawn towards each other, is termed the attraction of gravitation. The attraction which the earth exerts on all bodies near its surface, is called *terrestrial gravitation*, and the specific force with which any body is attracted, is termed its *weight*. All falling bodies tend towards the centre of the earth, in right lines; or, to speak more strictly, with reference to the spheroidal figure of the earth, in lines perpendicular to the surface of still water. It follows, therefore, that two falling bodies, on opposite parts of the earth, mutually fall towards each

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22. What is tenacity? From what does this quality arise? What elementary vegetable tissue is highly tenacious, and to what purpose is it consequently applied? How is the tenacity of metals ascertained?—23. What is meant by terrestrial gravitation? What is meant by the weight of a body? What is the tendency of all falling bodies, with respect to terrestrial gravitation? In what direction will two falling bodies from opposite parts of the earth tend, in respect to each other? In what direction will one from half way between them meet their line? How is this shown by the figure? Are the terms *up* and *down* relative or positive, in their meaning? What is understood by *down* in any part of the earth? Suppose a ball be let fall at twelve and then at six o'clock, in what direction would the lines of their descent meet each other? Suppose two balls to descend from opposite sides of the earth, what would be their direction in respect to each other?

other; and, upon the same principle, that a body falling at the distance of a quarter, instead of that of a half, of the earth's circumference from us, is carried in a direction exactly across, or at right angles to, the line above indicated. "This will be readily understood by Fig. 3, where the circle is supposed to be the circumference of the earth; A, the ball falling towards its upper surface, where we stand; B, a ball falling towards the opposite side of the earth, but ascending in respect to us; and D, a ball descending at the distance of a quarter of the circle, from the other two, and crossing the line of their direction at right angles. It will be obvious, therefore, that what we call *up* and *down* are merely relative terms, and that what is *down* in respect to us, is *up* in respect to those who live on the opposite side of the earth, and so the contrary. Consequently, *down* everywhere means towards the centre of the earth, and *up* from the centre of the earth; because all bodies descend towards the earth's centre, from whatever part they are let fall. This will be apparent when we consider, that as the earth revolves on its axis every 24 hours, we are carried with it through the points A, D, and B; and therefore, if a ball is supposed to fall from the point A, at 12 o'clock, and the same ball to fall again from the same point above the earth at 6 o'clock, the two lines of direction will be at right angles, as represented in the figure; for that part of the earth which was under A at 12 o'clock, will be under D at 6 o'clock, the earth having in that time performed one quarter of its daily revolution. At 12 o'clock at night, if the ball be supposed to fall again, its line of direction will be at right angles with that of its last descent, and consequently it will *ascend* in respect to the point on which it fell 12 hours before, because the earth would have then gone through one half her daily rotation, and the point A would be at B.

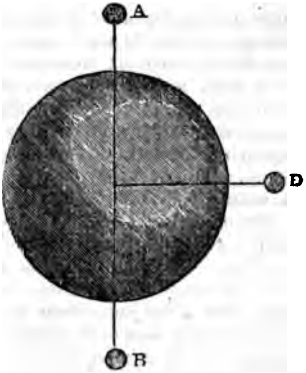

Fig. 3.

24. *Velocity of falling bodies.*—"The velocity or rapidity of every falling body is uniformly accelerated, or increased, in its approach towards the earth, from whatever height it falls. 1. If a rock is rolled from a steep mountain, its motion is at first slow and gentle, but as it proceeds downward, it moves with perpetually increased velocity, seeming to gather fresh speed every moment, until its force is such that every obstacle is overcome; trees and rocks are beat from its path, and its motion does not cease until it has rolled to a great distance on the plain. 2. The same principle of increased velocity as bodies descend from a height, is curiously illustrated by pouring molasses or thick syrup from an elevation to the ground. The bulky stream, of perhaps two inches in diameter, where it leaves the vessel, as it descends, is reduced to the size of a straw, or knitting needle; but what it wants in bulk is made up in velocity, for the small stream at the ground, will fill a vessel just as soon as the large one at the outlet. 3. For the same reason, a man may leap from a chair without danger, but if he jump from the house-top, his velocity becomes so much increased, before he reaches the ground, as to endanger his life by the blow.

25. "It is found by experiment, that the motion of a falling body is increased, or accelerated, in regular mathematical proportions. These increased proportions do not depend on the increased weight of the body, because it approaches nearer the centre of the earth, but on the constant operation of the force of gravity, which perpetually gives new impulses to the falling body, and increases its velocity. It has been ascertained by experiment, that a body, falling freely, and without resistance, passes through a space of 16 feet and 1 inch during the first second of time. Leaving out the inch, which is not necessary for our present purpose, the ratio of descent is as follows:—If the height through which a body falls in one second of time be known, the height which it falls in a proposed time may be computed. For since the height is proportional to the square of the time, the height through which it will fall in *two* seconds will be *four* times that which

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24. What is said concerning the motions of falling bodies? How is this increased velocity illustrated? Why is there any more danger in jumping from the house-top than from a chair?—25. What number of *feet does a falling body* pass through during the first second? How far *does it fall during the* next second? How far during the third, the *fourth, the fifth second?*

it falls through in *one* second; in *three* seconds it will fall through *nine* times that space; in *four* seconds, *sixteen* times that of the first second; in *five* seconds, *twenty-five* times, and so on in this proportion.

26. "It will be readily conceived, that solid bodies falling from great heights, must ultimately acquire an amazing velocity by this proportion of increase. An ounce ball of lead, let fall from a certain height towards the earth, would thus acquire a force ten or twenty times as great as when shot out of a rifle. By actual calculation it has been found that, were the moon to lose her projectile force, which counterbalances the earth's attraction, she would fall to the earth in four days and twenty hours, a distance of 240,000 miles. And were the earth's projectile force destroyed, it would fall to the sun in sixty-four days and ten hours, a distance of 95,000,000 of miles. Every one knows by his own experience the different effects of the same body falling from a great or a small height. A boy will toss up his leaden bullet and catch it with his hand, but he soon learns, by its painful effects, not to throw it too high. The effects of hail-stones on window-glass, animals, and vegetation, are often surprising, and sometimes calamitous illustrations of the velocity of falling bodies.

27. *Attraction proportionable to the matter.*—"If two bodies contain like quantities of matter, their approach will be equally rapid, and they will move through equal distances towards each other. But if the one be small and the other large, the small one will approach the other with a rapidity proportioned to the less quantity of matter it contains. It is easy to conceive, that if a man in one boat pull at a rope attached to another boat, the two boats, if of the same size, will move towards each other at the same rate; but if the one be large and the other small, the rapidity with which each moves will be in proportion to its size, the large one moving with as much less velocity as its size is greater. A man in a boat pulling a rope attached to a ship, seems only to move the boat,

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26. Would it be possible for a rifle ball to acquire a greater force by falling, than if shot from a rifle? How long would it take the moon to come to the earth according to the law of increased velocity? How long would it take the earth to fall to the sun? What familiar illustrations are given of the force acquired by the velocity of falling bodies? —27. Suppose one body moving towards another three times as large, *by the force of gravity*, what would be their proportional velocities? *How is this illustrated?*

but that he really moves the ship is certain, when it is considered, that a thousand boats pulling in the same manner would make the ship meet them half-way. It appears, therefore, that an equal force acting on bodies containing different quantities of matter, moves them with different velocities, and that these velocities are in an inverse proportion to their quantities of matter.

OF MOTION IN GENERAL.

28. *Laws of Motion.*—By the term *motion* is signified a continued change of place in bodies, with reference to a fixed point; and, according to the explanation, already given, of the universal property of matter, called *inertia* (§ 6,) the condition of motion is as natural to bodies as that of *rest*, or the opposite condition. Owing to the absence of volition, and the presence of inertia, every substance in nature presents a passive character, yielding itself to the operation of external causes, and wholly incapable of originating motion in itself, or of arresting any motion which may have been imparted to it. These and other fundamental laws of nature, in relation to rest and motion of matter, were announced by Newton in the three following propositions:—

1. Every body must persevere in its state of rest, or of uniform motion in a straight line, unless it be compelled to change that state by forces impressed upon it.
2. Every change of motion must be proportional to the impressed force, and must be in the direction of that straight line in which the force is impressed.
3. Action must always be equal and contrary to reaction; or the actions of two bodies upon each other must be equal, and their directions must be opposite.

Hence, in the language of philosophy, the power which communicates motion to a body, is called *force*. It is the force of gravity counteracting inertia, which determines the fall of a body towards the earth. The loaded waggon is set in motion by the muscular force of horses, the mill-wheel by the force of falling water, the vane by the force of wind; the motion of the steam-engine, and of various other machines, is maintained and regulated by the application of a fly-wheel.

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28. How do you define motion? State the three laws of motion. *What is that power called* which puts a body in motion? What would *be the consequence were all* motion to cease?

Without force, there could he no motion; without motion, there could be no rising or setting of the sun, no change of seasons, no fall of rain, no animal life.

29. "*Rest*, in the common meaning of the term, is the opposite of motion; but it is obvious that rest is often a relative term, since an object may be perfectly at rest with respect to some things, and in rapid motion in respect to others. Thus a man sitting on the deck of a steam-boat, may move at the rate of fifteen miles an hour, with respect to the land, and still be at rest with respect to the boat. And so, if another man were running on the deck of the same boat at the rate of fifteen miles the hour in a contrary direction, he would be stationary in respect to a fixed point, and still be running with all his might with respect to the boat.

30. *Velocity of motion.*—"Velocity is the rate of motion at which a body moves from one place to another, [and is estimated by comparing the distance with the time occupied in passing over it]. Velocity is independent of the weight or magnitude of the moving body—thus, a cannon-ball and a musket-ball, both flying at the rate of a thousand feet in a second, have the same velocities. 1. Velocity is said to be *uniform*, when the moving body passes over equal spaces in equal times: if a steam-boat move at the rate of ten miles every hour, her velocity is uniform; the revolution of the earth, from west to east, is a perpetual example of uniform motion. 2. Velocity is *accelerated*, when the rate of motion is constantly increased, and the moving body passes through unequal spaces in equal times. Thus, when a falling body moves sixteen feet during the first second, and forty-eight feet during the next second, its velocity is accelerated. A body falling from a height freely through the air, is the most perfect example of this kind of velocity. 3. *Retarded* velocity, is when the rate of motion of the body is constantly decreased, and it is made to move slower and slower. A ball thrown upwards into the air has its velocity constantly retarded by the attraction of gravitation, and, consequently, it moves slower every moment." 4. In cases of accelerated, and of

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29. In what respect is a man in a steam-boat at rest, and in what respect does he move?—30. What is velocity? When is velocity uniform? When is velocity accelerated? Give illustrations of these two kinds of velocity. What is meant by retarded velocity? Give an example of retarded velocity. What is the distinction between initial and final velocity? How are they both measured?

retarded velocity, a distinction is observed between the *initial* and the *final* velocity of a body: the former is exhibited by the body when it commences its motion; the latter only after the lapse of a certain time: both are measured by the space which the body would have passed over, in one second, with the uniform initial or final velocity, as the case may be.

31. *Force, or momentum of moving bodies.*—"The velocities of bodies are equal, when they pass over equal spaces in the same time; but the force with which bodies, moving at the same rate, overcome impediments, is in proportion to the quantity of matter they contain. This power, or force, is called the *momentum* of the moving body. Thus, if two bodies of the same weight move with the same velocity, their momenta will be equal. Two vessels, each of a hundred tons, sailing at the rate of six miles an hour, would overcome the same impediments, or be stopped by the same obstruction; their momenta would therefore be the same. The momentum of a body is found by multiplying its quantity of matter by its velocity. Thus, if the velocity be 2 and the weight 2, the momentum will be four. If the velocity be 6 and the weight of the body 4, the momentum will be 24." An iceberg moves slowly, but its momentum is prodigious, owing to its quantity of matter; a musket ball contains little matter, but its momentum is destructive, in consequence of its velocity. A body weighing only 3 pounds, and moving at a velocity of 300 feet in a second, will possess as much momentum as a body weighing 30 pounds, and moving at the rate of only 30 feet per second, for $300 \times 3 = 30 \times 30$.

32. *Action and reaction.*—"If a moving body strike an impediment, the force with which it strikes, and the resistance of the impediment, are equal. Thus, if a boy throw his ball against the side of the house, with the force of 3, the house resists it with an equal force, and the ball rebounds. If he throw it against a pane of glass with the same force, the glass having only the power of 2 to resist, the ball will go through the glass, still retaining one-third of its force. From observations made on the effects of bodies striking each other, it is found that action and reaction are equal; or, in

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31. What is meant by the momentum of a body? When will the momenta of two bodies be equal? Give an example. By what rule is the momentum of a body found?—32. When a moving body strikes an impediment, which receives the greater shock? What is the law of action and reaction? How is this illustrated?

other words, that force and resistance are equal. Thus, when a moving body strikes one that is at rest, the body at rest returns the blow with equal force. This is illustrated by the well known fact, that if two persons strike their heads together, one being in motion, and the other at rest, they are both equally hurt.

33. "The philosophy of action and reaction is finely illustrated by a number of ivory balls, suspended by threads, as in Fig. 4, so as to touch each other. If the ball A be drawn from the perpendicular, and then let fall, so as to strike the one next to it, the motion of the falling ball will be communicated through the whole series, from one to the other. None of the balls, except F, will, however, appear to move. This will be understood, when we consider that the reaction of B is just equal to the action of A, and that each of the other balls, in like manner, acts and reacts on the other, until the motion of A arrives at F, which, having no impediment, or nothing to act upon, is itself put in motion. It is, therefore, reaction which causes all the balls except F to remain at rest. It is by a modification of the same principle, that rockets are impelled through the air. The stream of expanded air, or the fire which is emitted from the lower end of the rocket, not only propels against the rocket itself, but against the atmospheric air, which, reacting against the air so expanded, sends the rocket along.

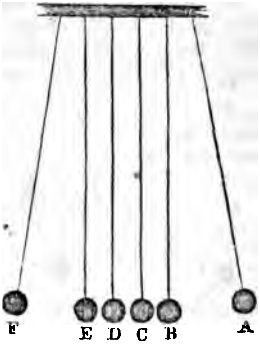

Fig. 4.

34. *Reflected motion.*—"The kind of motion now to be considered is that which is produced when bodies are turned out of a straight line by some force, independent of gravity. A single force, or impulse, sends the body directly forward, but another force not exactly coinciding with this, will give

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33. When one of the ivory balls strikes the other, why does the most distant one only move? On what principle are rockets impelled through the air?—34. What is the motion called, when a body is turned out of *a straight line* by another force? What illustrations can you give of *reflected motion?*

it a new direction, and bend it out of its former course. If, for instance, two moving bodies strike each other obliquely, they will both be thrown out of the line of their former direction. This is called *reflected* motion, because it observes the same laws as reflected light. The bounding of a ball; the skipping of a stone over the smooth surface of a pond; and the oblique direction of an apple, when it touches a limb in its fall, are examples of reflected motion.

35. "By experiments on this kind of motion, it is found that moving bodies observe certain laws, in respect to the direction they take in rebounding from any impediment they happen to strike. Thus, a ball, striking on the floor, or wall of a room, makes the same angle in leaving the point where it strikes, that it does in approaching it. 1. Suppose A B, Fig. 5, to be a marble slab, or floor, and C to be an ivory ball, which has been thrown towards the floor in the direction of the line C E; it will rebound in the direction of the line E D, thus making the two angles F and G exactly equal. 2. If the ball approached the floor under a larger or smaller angle, its rebound would observe the same rule. Thus, if it fell in the line H K, Fig. 6, its rebound would be in the line K I, and if it were dropped perpendicularly from L to K, it would return in the same line to L. The angle which the ball makes with the perpendicular L K, in its approach to the floor, is called the *angle of incidence*, and that which it makes in departing

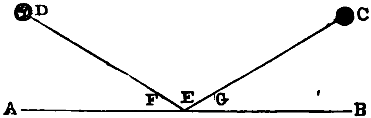

Fig. 5.

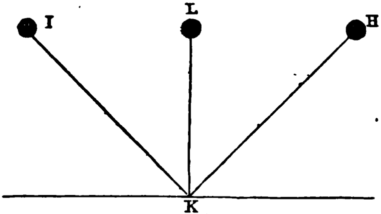

Fig. 6.

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35. What laws are observed in reflected motion? Suppose a ball to be thrown on the floor in a certain direction, what rule will it observe in *rebounding? What is the* angle called which the ball makes in approach*ing the floor? What is the* angle called which it makes in leaving the *floor? What is the difference* between these angles?

from the floor in the same line, is called the *angle of reflection*, and these angles are always equal to each other.

36. *Circular motion.*—"*Circular motion* is the motion of a body in a ring, or circle, and is produced by the action of two forces. By one of these forces the moving body tends to fly off in a straight line, while, by the other, it is drawn towards the centre, and thus it is made to revolve, or move round in a circle. The force by which a body tends to go off in a straight line is called the *centrifugal force;* that which keeps it from flying away, and draws it towards the centre, is called the *centripetal force.* Bodies moving in circles are constantly acted upon by these two forces. If the centrifugal force should cease, the moving body would no longer perform a circle, but would directly approach the centre of its own motion. If the centripetal force should cease, the body would instantly begin to move off in a straight line, this being, as we have explained, the direction which all bodies take when acted on by a single force.

37. "This will be obvious by Fig. 7. Suppose A to be a cannon ball, tied with a string to the centre of a slab of smooth marble, and suppose an attempt be made to push this ball with the hand in the direction of B; it is obvious that the string would prevent its going to that point; but would keep it in the circle. In this case, the string is the *centripetal force.* Now, suppose the ball to be kept revolving with rapidity, its velocity and weight will occasion its *centrifugal force;* and if the string were cut, when the ball was at the point C for instance, this force would carry it off in the line towards B.

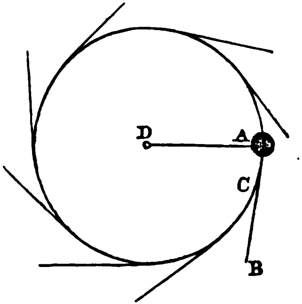

Fig. 7.

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36. What is circular motion? How is this motion produced? What is the centrifugal force? What is the centripetal force? Suppose the centrifugal force should cease, in what direction would the body move? Suppose the centripetal force should cease, where would the body go? —37. Explain Fig. 7. What constitutes the centrifugal force of a body moving round in a circle? How is this illustrated?

38. "The greater the velocity with which a body moves round in a circle, the greater will be the force with which it will fly off in a right line. Thus, when a person wishes to sling a stone to the greatest distance, he whirls it round with the greatest possible rapidity before he lets it go. Before the invention of other warlike instruments, soldiers threw stones in this manner with great force, and dreadful effects. The line about which a body revolves, is called its *axis of motion*. The point round which it turns, or on which it rests, is called the *centre of motion*. In Fig. 7, the point D, to which the string is fixed, is the centre of motion. In the spinning top, a line through the centre of the handle to the point on which it turns, is the axis of motion.

CENTRE OF GRAVITY.

39. "The *centre of gravity*, in any body or system of bodies, is that point upon which the body, or system of bodies, acted upon only by gravity, will balance itself in all positions. The centre of gravity, in a wheel made entirely of wood, and of equal thickness, would be exactly in the middle, or in its ordinary centre of motion. But if one side of the wheel were made of iron, and the other part of wood, its centre of gravity would be changed to some point, aside from the centre of the wheel. Thus, the centre of gravity in the wooden wheel, Fig. 8, would be at the axis on which it turns; but were the arm A of iron, its centre of motion and of gravity would no longer be the same, but, while the centre of motion remained as before, the centre of gravity would fall to the point A. Thus the centres of motion and of gravity, though often at the same point, are not always so.

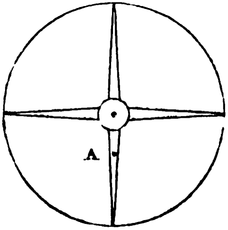

Fig. 8.

40. "When the body is shaped irregularly, or there are

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38. What is the axis of motion? What is the centre of motion? Give illustrations.—39. Where is the centre of gravity in a body? Where is the centre of gravity in a wheel made of wood? If one side is made of wood, and the other of iron, where is the centre of gravity? Are the centres of motion and of gravity always the same?—40. When *two bodies are connected*, as by a bar between them, where is the centre *of gravity?*

two or more bodies connected, the centre of gravity is the point on which they will balance without falling. If the two balls A and B, Fig. 9, weigh each four pounds, the centre of gravity will be a point on the bar equally distant from each. But if one of the balls be heavier than the other, then the centre of gravity will, in proportion, approach the larger ball. Thus, in Fig. 10, if C weigh two pounds, and D eight pounds, the centre of gravity will be four times the distance from C that it is from D.

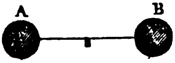

Fig. 9.

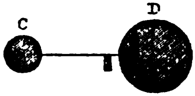

Fig. 10.

41. "In a body of equal thickness, as a board, or a slab of marble, but otherwise of an irregular shape, the centre of gravity may be found by suspending it, first from one point, and then from another, and marking, by means of a plumb line, the perpendicular ranges from the point of suspension. The centre of gravity will be the point where these two lines cross each other. Thus, if the irregular-shaped piece of board, Fig. 11, be suspended by making a hole through it at the point A, and at the same point suspending the plumb line C, both board and line will hang in the position represented in the figure. Having marked this line across the board, let it be suspended again in the position of Fig. 12, and the perpendicular line again marked. The point where these lines cross each other, is the centre of gravity, as seen by Fig. 13.

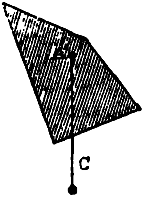

Fig. 11.

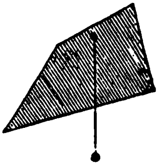

Fig. 12.

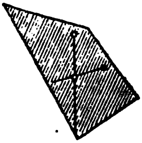

Fig. 13.

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41. In a board of irregular shape, by what method is the centre gravity found?

42. "It is often of great consequence, in the concerns of life, that the subject of gravity should be well considered, since the strength of buildings, and of machinery, often depends chiefly on the gravitating point. Common experience teaches, that a tall object, with a narrow base, or foundation, is easily overturned; but common experience does not teach the reason, for it is only by understanding principles that practice improves experiment. An upright object will fall to the ground when it leans so much that a perpendicular line from its centre of gravity falls beyond its base. A tall chimney, therefore, with a narrow foundation, such as is commonly built at the present day, will fall with a very slight inclination. Now, in falling, the centre of gravity passes through the part of a circle, the centre of which is at the extremity of the base on which the body stands. This will be comprehended in Fig. 14. Suppose the figure to be a block of marble, which is to be turned over, by lifting at the corner A, the corner B would be the centre of its motion, or the point on which it would turn. The centre of gravity, C, would therefore describe the part of a circle, of which the corner B is the centre. It will be obvious, after a little consideration, that the greatest difficulty we should find in turning over a square block of marble, would be, in first raising up the centre of gravity, for the resistance will constantly become less, in proportion as the point approaches a perpendicular line over the corner B, which having passed, it will fall by its own gravity.

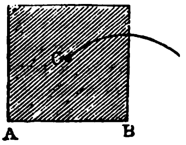

Fig. 14.

43. "The difficulty of turning over a body of a particular form, will be more strikingly illustrated by the figure of a triangle, or low pyramid. In Fig. 15, the centre of gravity is so low, and the base so broad, that in turning it over, a great proportion of its whole weight must be raised. Hence we see the firmness of the pyramid in theory,

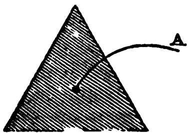

Fig. 15.

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42. In what direction must the centre of gravity be from the outside of the base, before the object will fall? In falling, the centre of gravity *passes through part* of a circle; where is the centre of this circle? In *turning over a body,* why does the force required constantly become less *and less?—43. Why is less* force required to overturn a cube, or square, *than a pyramid of the* same weight?

and experience proves its truth; for buildings are found to withstand the effects of time, and the commotions of earthquakes, in proportion as they approach this figure. The most ancient monuments of the art of building, now standing, the pyramids of Egypt, are of this form.

44. *Equilibrium.*—"When two forces counteract, or balance each other, they are said to be in *equilibrium.* To produce equilibrium, it is, therefore, only necessary that the weights on each side of the support should mutually counteract each other, or, if set in motion, that their momenta should be equal. A pair of scales are in equilibrium when the beam is in a horizontal position. To produce equilibrium in solid bodies, therefore, it is only necessary to support the centre of gravity. If a body, or several bodies connected, be suspended by a string, as in Fig. 16, the point of support is always in a perpendicular line above the centre of gravity. The plumb line D, cuts the bar connecting the two balls at this point. Were the two weights in this figure equal, it is evident that the hook, or point of support, must be in the middle of the string, to preserve the horizontal position. When a man stands on his right foot, he keeps himself in equilibrium by leaning to the right, so as to bring his centre of gravity in a perpendicular line over the foot on which he stands.

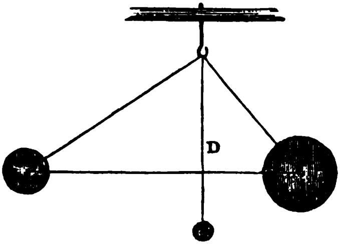

Fig. 16.

CURVILINEAR OR BENT MOTION.

45. "In *curvilinear motion* the direction of the body is neither straight forward nor diagonal, but through a line which is curved. This kind of motion may be in any direc-

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44. What is meant by equilibrium? To produce equilibrium, must the weights be equal? When is a pair of scales in equilibrium? When a body is suspended by a string, where must the support be with respect *to the point* of gravity?—45. What is meant by curvilinear motion *What are examples* of this kind of motion? What two forces prod *this motion?*

tion; but when it is produced in part by gravity, its direction is always towards the earth. A stream of water from an aperture in the side of a vessel, as it falls towards the ground, is an example of a curved line; and a body passing through such a line, is said to have *curvilinear* motion. Any body projected forward, as a cannon ball or rocket, falls to the earth in a curved line. It is the action of gravity across the course of the stream, or the path of the ball, which bends it downwards, and makes it form a curve. This motion is therefore the result of two forces, that of projection and that of gravity. The shape of the curve will depend on the velocity of the stream or ball. When the pressure of the water is great, the stream near the vessel is nearly horizontal, because its velocity is in proportion to the pressure. When a ball first leaves the cannon, it describes but a slight curve, because its projectile velocity is then greatest.

46. "The curves described by jets of water, under different degrees of pressure, are readily illustrated by tapping a tall vessel in several places, one above the other. Suppose

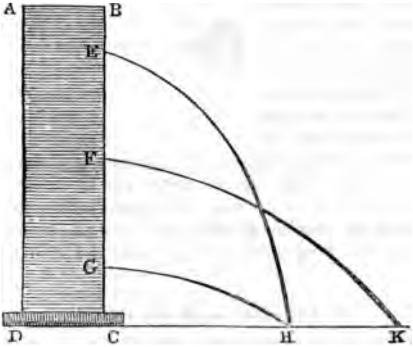

Fig. 17.

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46. On what does the shape of the curve depend? How are the curves described by jets of water illustrated? What difference is there in respect to the time taken by a body to reach the ground, whether the curve be great or small? Why do bodies forming different curves from the same height, reach the ground at the same time? Suppose two balls, one *flying at the rate of a thousand*, and the other at the rate of a hundred *feet per second, which would* descend most during the second?

Fig. 17 to be such a vessel fillėd with water, and pierced as represented, the streams will form curves, differing from each other, as seen in the figure. The action of gravity being always the same, the shape of the curve described, as just stated, must depend upon the velocity of the moving body; but whether the projectile force be great or small, the moving body, if thrown horizontally, will reach the ground from the same height in the same time. This, at first thought, would seem improbable, for, without consideration, most persons would assert, very positively, that if two cannons were fired from the same spot, at the same instant, and in the same direction, one of the balls falling half a mile, and the other a mile distant, the ball which went to the greater distance would take the longer time in performing its journey. But it must be remembered that the projectile force does not in the least interfere with the force of gravity. A ball flying horizontally at the rate of a thousand feet per second, is attracted downwards with precisely the same force as one flying only a hundred feet per second, and must therefore descend the same distance in the same time.

47. "The distance to which a ball will go depends on the force of impulse given it the first instant, and consequently on its projectile velocity. If it move slowly, the distance will be short; if more rapidly, the space passed over will be greater. It makes no difference, then, in respect to the descent of the ball, whether its projectile motion be fast or slow, or whether it move forward at all. This is demonstrated by experiment. Suppose a cannon to be loaded with a ball, and placed on the top of a tower, at such a height from the ground that it would take just three seconds for a cannon ball to descend from it to the ground if let fall perpendicularly. Now, suppose the cannon to be fired in an exact horizontal direction, and at the same instant the ball to be dropped towards the ground, they will both reach the ground at the same instant, provided its surface be a horizontal plane from the foot of the tower to the place where the projected ball strikes.

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47. Does it make any difference in respect to the descent of the ball, whether it has a projectile motion or not? Suppose then, one ball be fired from a cannon, and another let fall from the same height at the same instant, would they both reach the ground at the same time? Explain *Fig. 18, showing the reason why the two balls will reach the ground at the same time.* Why does the ball approach the earth more rapidly *in the last part of the curve, than in the first part?*

This will be made plain by Fig. 18, where A D is the perpendicular line of the descending ball, A G the curvilinear path of that projected from the cannon, and D G the horizontal line from the foot of the tower.

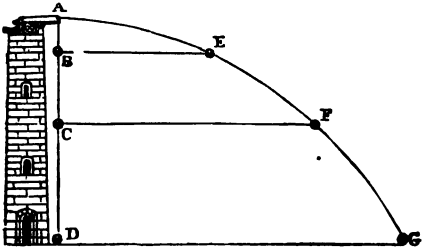

Fig. 18.

The reason why the two balls will reach the ground at the same time is easily comprehended. During the first second, suppose that the ball which is dropped reaches B; during the next second it falls to C, and at the end of the third second it strikes the ground. Meantime, the ball shot from the cannon is projected forward with such velocity, as to reach E in the same time that the other is falling to B. But the projected ball falls downwards exactly as fast as the other, for it meets the line B E, which is parallel to the horizon, at the same instant. During the next second, the projected ball reaches F, while the other arrives at C; and here again they have both descended through the same downward space, as is seen by the line C F, which is parallel with the other. During the third second the ball from the cannon will have nearly spent its projectile force, and therefore, its motion downward will be greater, while its motion forward will be less than before. The reason of this will be obvious, when it is considered, that in respect to gravity, both balls follow exactly the same law, and fall through equal spaces in equal times. Therefore, as the falling ball descends through the greatest space during the last second, so that from the cannon having now a less projectile motion, its downward motion is more direct, and, like all falling bodies, its velocity is increased as it approaches the earth.

48. "From these principles it may be inferred that the horizontal motion of a body through the air, does not in the least interfere with its gravitating motion towards the earth; and therefore that a rifle ball, or any other body projected forward horizontally, will reach the ground in exactly the same period of time, as one that is let fall perpendicularly from the same height. The two forces acting on bodies which fall through curved lines, are the same as the centrifugal and centripetal forces, already explained; the centrifugal, in the case of the ball, being caused by the powder; the centripetal, being the action of gravity.

PENDULUM.

49. "A *pendulum* is a heavy body, as a piece of brass or lead, suspended by a wire or cord, so as to swing backwards and forwards. When a pendulum swings, it is said to *vibrate*, and that part of a circle through which it vibrates is called its *arc*. The times of the vibration of a pendulum are very nearly equal, whether it pass through a greater or less part of its arc. Suppose A and B, Fig. 19, to be two pendulums of equal length, and suppose the weights of each are carried, the one to C, and the other to D, and both let fall at the same instant; their vibrations would be equal in respect to time, the one passing through its arc from C to E, and back again, in the same time that the other passes from D to F, and back again. The reason of this appears to be, that when the pendulum is raised high, the action of gravity draws it more directly downwards, and it therefore acquires, in falling, a greater comparative velocity than is proportioned

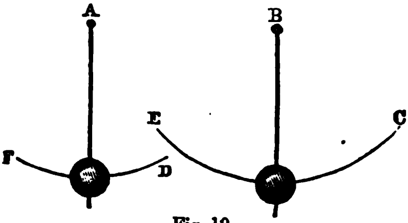

Fig. 19.

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48. What is the force called which throws a ball forward? What is that called which brings it to the ground?—49. What is a pendulum? What is meant by the vibration of a pendulum? What is that part of a circle called, through which it swings? Why does a pendulum vibrate *in equal time*, whether it goes through a small or large part of its arc? *State the law of* the vibration of pendulums.

to the trifling difference of height." From the facts above stated, the following *law* may be deduced:—Pendulums of equal length vibrate, or oscillate, at the same place in equal times, and are said to be *isochronous*. The heights to which such pendulums are elevated, must not differ considerably, nor must they be raised more than 10° beyond the perpendicular.

50. "In the common clock, the pendulum is connected with wheel work, to regulate the motions of the hands, and with weights, by which the whole is moved. The vibrations of the pendulum are numbered by a wheel having sixty teeth, which revolves once in a minute. Each tooth, therefore, answers to one swing of the pendulum, and the wheel moves forward one tooth in a second. Thus the second hand revolves once in every sixty beats of the pendulum, and as these beats are seconds, it goes round once in a minute. By the pendulum, the whole machine is regulated, for the clock goes faster or slower according to its number of vibrations in a given time. The number of vibrations which a pendulum makes in a given time, depends upon its length, because a long pendulum does not perform its journey to and from the corresponding points of its arc so soon as a short one. As the motion of the clock is regulated entirely by the pendulum, and as the number of vibrations are as its length, the least variation in this respect will alter its rate of going. To beat seconds, its length must be about 39 inches. In the common clock, the length is regulated by a screw, which raises or lowers the weight. But as the rod to which the weight is attached is subject to variations of length, in consequence of the change of the seasons, being contracted by cold, and lengthened by heat, the common clock goes faster in winter than in summer.

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50. Describe the common clock. How many vibrations has the pendulum in a minute? On what depends the number of vibrations which a pendulum makes in a given time? What is the medium length of a pendulum beating seconds? Why does a common clock go faster in winter than in summer?

CHAP. II.

OF MECHANICS.

51. "*Definitions.*—In mechanics, as well as in other sciences, there are words which must be explained, either because they are common words used in a peculiar sense, or because they are terms of art, not in common use.

(1.) "*Force* is the means by which bodies are set in motion, kept in motion, and when moving, are brought to rest. The force of gunpowder sets the ball in motion, and keeps it moving, until the force of resisting air, and the force of gravity, bring it to rest.

(2.) "*Power* is the means by which the machine is moved, and the force gained. Thus we have horse power, water power, and the power of weights.

(3.) "*Weight* is the resistance, or the thing to be moved by the force of the power. Thus, the stone is the weight to be moved by the force of the lever, or bar.

(4.) "*Fulcrum*, or prop, is the point or part on which a thing is supported, and about which it has more or less motion. In raising a stone, the thing on which the lever rests, is the fulcrum."

52. In mechanics, there are six *simple* machines, commonly called the *mechanical powers*, viz. the lever, the pulley, the wheel and axle, the inclined plane, the wedge, and the screw. All the different *compound* machines, however mixed or complex their construction, consist only of various combinations of these few individual powers.

I. THE LEVER.

53. *First kind of lever.*—Any inflexible rod, or bar, which is used in raising a weight, or surmounting a resistance, by being placed on a fulcrum, or prop, becomes a lever. This machine is the most simple of all the mechanical powers, and is therefore in universal use. Fig. 20 represents a straight lever, or *handspike*; called also a *crow-bar*, which

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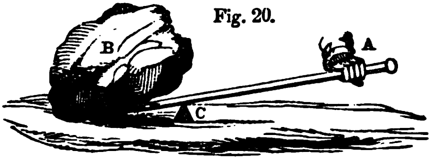
51. What is meant by force in mechanics? What is meant by power? What is understood by weight? What is the fulcrum?—52. Enumerate the simple mechanical powers.—53. What is a lever? What is the simplest of all mechanical powers? Explain Fig. 20. *Which is* the weight? Where is the fulcrum? Where is the powe *applied?* What is the power in this case?

is commonly used in raising and moving stone and other heavy bodies. The block B is the *weight* or resistance, A is the *lever*, and C the *fulcrum*. The *power* is the hand, or weight of a man, applied at A, to depress that end of the lever, and thus to raise the weight. It will be observed, that by this arrangement, the application of a small power may be used to overcome a great resistance.

Fig. 20.



54. "The force to be obtained by the lever, depends on its length, together with the power applied, and the distance of the weight and power from the fulcrum. Suppose, Fig. 21, that A is the lever, B the fulcrum, D the weight to be raised, and C the power. Let D be considered three times as heavy as C, and the fulcrum three times as far from C as it is from D; then the weight and power will exactly balance each other. Thus, if the bar be four feet long, and the fulcrum three feet from the end, then three pounds on the long arm, will weigh just as much as nine pounds on the short arm, and these proportions will be found the same in all cases.

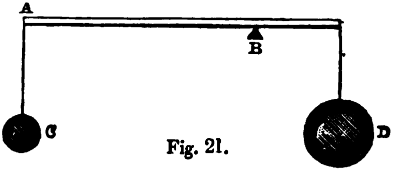


Fig. 21.

55. "When two weights balance each other, the fulcrum

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54. On what does the force to be obtained by the lever depend? Suppose a lever four feet long, and the fulcrum one foot from the end, what number of pounds will balance each other at the ends?—55. When weights balance each other, at what point between them must the fulcrum be? Suppose a weight of 16 pounds on the short arm of a lever is counterbalanced by 4 pounds in the middle of the long arm, what power would balance this weight at the end of the lever? Suppose the fulcrum to be moved to the middle of the lever, what power would then be equal to 16 pounds.

is always the centre of gravity between them, and therefore, to make a small weight raise a large one, the fulcrum must be placed as near as possible to the large one, since the greater the distance *from the fulcrum the small weight* or power is placed, the greater will be its force. Suppose the weight B, Fig. 22, to be sixteen pounds, and suppose the fulcrum to be placed so near it, as to be raised by the power A, of four pounds, hanging equally distant from the fulcrum and the end of the lever. If now the power A be removed, and another of two pounds, C, be placed at the end of the lever, its force will be just equal to A, placed at the middle of the lever. But let the fulcrum be moved along to the middle of the lever, with the weight of sixteen pounds still suspended to it, it would then take another weight of sixteen pounds, instead of two pounds, to balance it, Fig. 23. Thus, the power which would balance sixteen pounds, when the fulcrum is in one place, must be exchanged for another power weighing eight times as much, when the fulcrum is in another place.

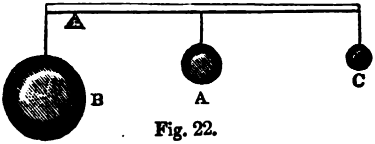

Fig. 22.

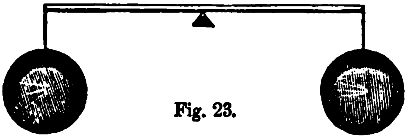

Fig. 23.

56. "A common scale-beam, used for weighing, is a lever, suspended at the centre of gravity, so that the two arms balance each other. Hence the machine is called a *balance.* The fulcrum, or what is called the *pivot*, is sharpened, like a wedge, and made of hardened steel, so as much as possi-

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56. In the common scale-beam, where is the fulcrum? In what position ought the scale-beam to hang? How may a fraudulent scale-beam be made? How may the cheat be detected?

ble to avoid friction. A dish is suspended by cords to each end or arm of the lever, for the purpose of holding the articles to be weighed. When the whole is suspended at the point A, Fig. 24, the beam or lever ought to remain in a horizontal position, one of its ends being exactly as high as the other. If the weights in the two dishes are equal, and the support exactly in the centre, they will always hang as represented in the figure. A very slight variation of the point of support towards one end of the lever, will make a difference in the weights employed to balance each other. In weighing a pound of sugar, with a scale beam of eight inches long, if the point of support is half an inch too near the weight, the buyer would be cheated nearly one ounce, and consequently nearly one pound in every sixteen pounds. This fraud might instantly be detected by changing the places of the sugar and weight, for then the difference would be quite material, since the sugar would then seem to want twice as much additional weight as it did really want.

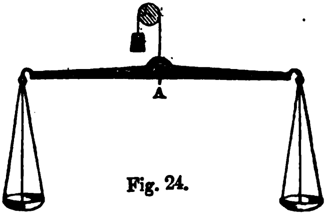

Fig. 24.

57. "The *steel-yard* differs from the balance, in having its support near one end, instead of in the middle, and also in having the weights suspended by hooks, instead of being placed in a dish. If we suppose the beam to be seven inches long, and the hook, C, Fig. 25, to be one inch from the end,

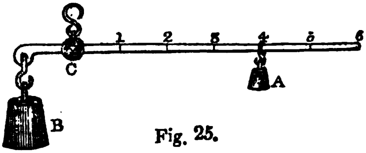

Fig. 25.

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57. How does the steel-yard differ from the balance?

then the pound weight, A, will require an additional pound at B, for every inch that it is moved from it. This, however, supposes that the bar will balance itself, before any weights are attached to it.

58. "In the kind of lever described, the weight to be raised is on one side of the fulcrum, and the power on the other. Thus *the fulcrum is between the power and the weight.*

59. *Second kind of lever.*—"There is another kind of lever, in the use of which the weight is placed between the fulcrum and the hand. In other words, the weight to be lifted, and the power by which it is moved, are on the same side of the prop. This arrangement is represented by Fig. 26, where W is the weight, L the lever, F the fulcrum, and P a pulley, over which a string is thrown, and a small weight suspended, as the power. In the common use of a lever of the first kind, the force is gained by bearing down the long arm of the lever, which is called *prying.* In the second kind, the force is gained by carrying the long arm in a contrary direction, or upward, and this is called *lifting.* Levers of the second kind are not so common as the first, but are frequently used for certain purposes. The oars of a boat are examples of the second kind. The water against which the blade of the oar pushes, is the fulcrum, the boat is the weight to be moved, and the hands of the man the power. Two men carrying a load between them on a pole, is also an example of this kind of lever. Each man acts as the power in moving the weight, and at the same time each becomes the

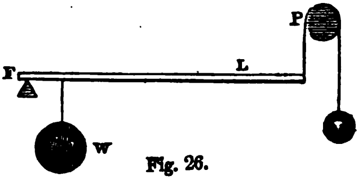

Fig. 26.

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58. In the first kind of lever, where is the fulcrum, in respect to the weight and power?—59. In the second kind, where is the fulcrum, in respect to the weight and power? What is the action of the first kind called? What is the action of the second kind called? Give examples of the second kind of lever. In rowing a boat, what is the fulcrum, what *the* weight, and what the power? What other illustrations of this principle are given?

fulcrum in respect to the other. If the weight happen to slide on the pole, the man towards whom it goes, has to bear more of it in proportion as its distance from him is less than before. A load at A, Fig. 27, is borne equally by the two men, being equally distant from each other; but at B, three quarters of its weight would be on the man at that end, because three quarters of the length of the lever would be on the side of the other man.

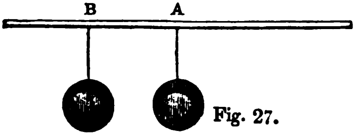

Fig. 27.

60. *Third kind of lever.*—"In the third and last kind of lever, the weight is placed at one end, the fulcrum at the other end, and the power between them, or the hand, is between the fulcrum and the weight to be lifted. This is represented by Fig. 28, where C is the fulcrum, A the power, suspended over the pulley B, and D is the weight to be raised. This kind of lever works at great disadvantage, since the power must be greater than the weight. It is therefore seldom used, except in cases where velocity and not force is required. In raising a ladder from the ground to the roof of a house, men are obliged sometimes to make use of this principle, and the great difficulty of doing it, illustrates the mechanical disadvantage of this kind of lever." But as the purpose to be fulfilled is not

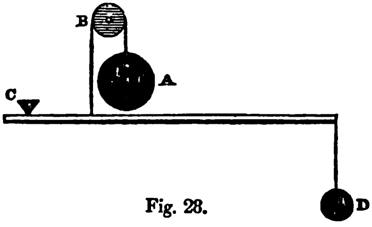

Fig. 28.

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60. In the third kind of lever, where are the respective places of the *weight, power, and fulcrum?* What is the disadvantage of this kind of *lever? Give an example* of the use of the third kind of lever.

always to increase the power of the agent, this kind of lever may be very usefully employed in machinery, where the employment of every species of motion is required. Thus, in turning, in weaving, in spinning, and in various kinds of manufacture, where great velocity, and not great force is required, and where the hands of the workman are occupied with the more important parts of the work, this kind of lever is employed with obvious advantage, the feet being engaged to give motion to the machinery.

61. "We have now described three kinds of levers, and to make the difference between them still more obvious, and to avoid all confusion, we will here compare them together. In the first kind, the weight, or resistance, is on the short arm of the lever, the power, or hand, on the long arm, and the fulcrum between them. In the second kind, the weight is between the fulcrum and the hand, or power; and, in the third kind, the hand is between the fulcrum and the weight.

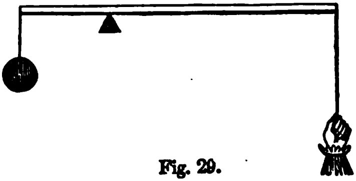

Fig. 29.

In Fig. 29, the weight and hand both act downwards. In 30, the weight and hand act in contrary directions, the hand upwards and the weight downwards, the weight being be-

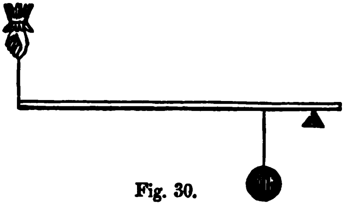

Fig. 30.

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61. **In what direction do the hand and weight act in the first kind of *lever?* In what direction do they act in the second kind? In what *direction* do they act in the third kind?**

tween them. In 31, the hand and weight also act in contrary directions, but the hand is between the fulcrum and the weight.

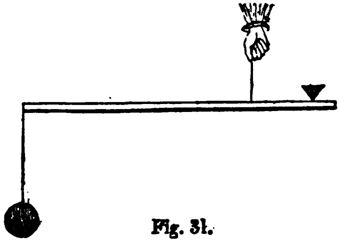

Fig. 31.

II. WHEEL AND AXLE.

62. The mechanical power next to the lever in simplicity, is the *wheel and axle.** It is, however, much more complex than the lever. It consists of a cylinder B, Fig. 32, which revolves about its axis, having a wheel A of larger diameter fixed to it. The weight C is suspended by a cord, which is wound round the axle. The power, exerted by a man turning the crooked arm, or winch, at one extremity of the axle, acts on the periphery of the wheel. When the machine is in operation, the wheel will take up, or throw off, as much more rope than the axle, as its circumference is greater. If the circumference of the wheel is four times that of the axle, then it will take up, or throw off, rope four times as fast. And because the circumference of the wheel is four times as

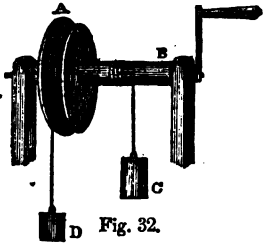

Fig. 32.

62. What is the next simple mechanical power to the lever? Describe this machine. Explain Fig. 32. When are the power and the weight in this machine in equilibrium?

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* The term *axle* is employed in accordance with the name of the mechanical *power, but it is not a correct term.* The word axis, or axle, denotes in mechanics, *the straight line, real or imaginary,* about which a body turns. The machine *would, therefore, be more* properly described as consisting of a cylinder, which *revolves upon its axis,* having a wheel of larger diameter fixed to it.

great as that of the axle, 1 pound suspended at D will balance 4 pounds suspended at C. Consequently, in this machine, the power and the weight are in equilibrium, when the former is to the latter as the radius of the axle is to that of the wheel. This will be made evident by the following considerations. When the power has turned the wheel round once, the axle has also undergone one revolution. The power has then traversed a space indicated by the circumference of the wheel, whilst the weight has been raised a height equal to the perimeter of the axle. Hence it appears that the velocity of the power is to that of the weight as the circumference of the wheel is to that of the axle, *i. e.*, as their radii.

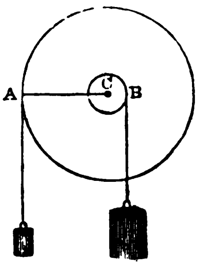

Fig. 33.

63. The principle of this machine is that of the lever. The definition and illustrations already given of the lever, exhibit this machine in its character of a simple bar, which is moveable in some part upon a prop or fulcrum. In the wheel and axle, it will be seen how a lever acts when it is moveable on or about a fixed axis. When a lever is moveable upon an axis, and is capable of being turned completely round, it assumes the character of the diameter of a wheel. This will be made evident by consideration of Fig. 33. "This figure represents the machine endwise, so as to shew in what manner the lever operates. The two weights hanging in opposition to each other, the one on the wheel at A, and the other on the axle at B, act in the same manner as if they were connected by the horizontal lever A B, passing from one to the other, having the common centre C as a fulcrum between them. The wheel and axle therefore acts like a constant succession of levers, the long arm being half the diameter of the wheel, and the short one half the diameter of the axle; the common centre of both being the fulcrum. The wheel and axle has therefore been called the *perpetual* lever.

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63. On what principle does this machine act? In Fig. 33, which is *the fulcrum*, and which the two arms of the lever? What is the *machine called*, in reference to the principle on which it acts?

64. "The wheel and axle, under different forms, is applied to a variety of common purposes. The *capstan*, in universal use on board of ships and other vessels, is an axle placed upright, with a head or drum, A, Fig. 34, pierced with holes for the levers, B, C, D. The weight is drawn by the rope E, passing two or three times round the axle, to prevent its slipping. This is a very powerful and convenient machine. When not in use, the levers are taken out of their places and laid aside; and when great force is required, two or three men can push at each lever.

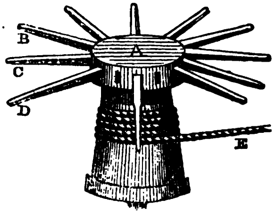

Fig. 34.

65. "The *common windlass* for drawing water is another modification of the wheel and axle. The *winch*, or *crank*, by which it is turned, is moved around by the hand, and there is no difference in the principle whether a whole wheel is turned or a single spoke. The winch, therefore, answers to the wheel, while the rope is taken up, and the weight raised by the axle, as already described.

66. "In cases where great weights are to be raised, and it is required that the machine should be as small as possible, on account of room, the simple wheel and axle, modified as represented by Fig. 35, is sometimes used. The axle may

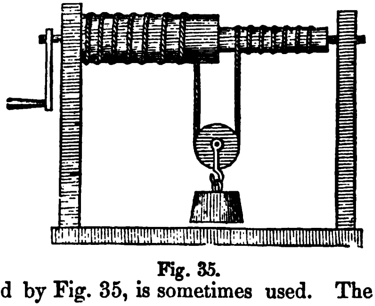

Fig. 35.

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64. What is the capstan? Where is it chiefly used? What are the *peculiar advantages* of this form of the wheel and axle?—65. In the *common windlass*, what part answers to the wheel?—66. Explain Fig. 35. *Why is the rope* shortened. and the weight raised?

be considered in two parts, one of which is larger than the other. The rope is attached by its two ends to the axle, as seen in the figure. The weight to be raised is attached to a small pulley or wheel, round which the rope passes. The elevation of the weight may be thus described:—Upon turning the axle, the rope is coiled around the larger part, and at the same time it is thrown off the smaller part. At every revolution, therefore, a portion of the rope will be drawn up equal to the circumference of the thicker part, and at the same time a portion equal to that of the thinner part will be let down. On the whole, then, one revolution of the machine will shorten the rope where the weight is suspended just as much as the difference between the circumference of the two parts.

67. *System of wheels.*—"As the wheel and axle is only a modification of the simple lever, so a system of wheels acting on each other, and transmitting the power to the resistance, is only another form of the compound lever. Such a combination is shewn at Fig. 36. The first wheel, A, by means of the teeth, or cogs around its axle, moves the second wheel, B, with a force equal to that of a lever, the long arm of which extends from the centre of the wheel and axle to the circumference of the wheel, where the power, P, is suspended, and the short arm from the same centre to the ends of the cogs.

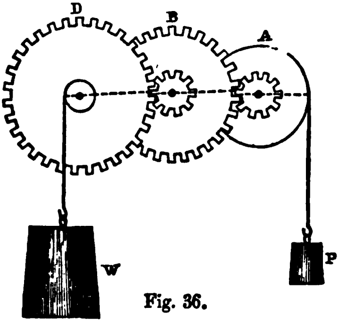

Fig. 36.

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67. On what principle does a system of wheels act, as represented in Fig. 36. Explain Fig. 36, and show how the power P *is transferred by the action of levers to* W.

The dotted line, C, passing through the centre of the wheel, A, shews the position of the lever, as the wheel now stands. The centre on which both wheels turn, it will be obvious, is the fulcrum of this lever. As the wheel turns, the short arm of this lever will act upon the long arm of the next lever by means of the teeth on the circumference of the wheel B, and this again through the teeth on the axle of B, will transmit its force to the circumference of the wheel D, and so by the short arm of the third lever to the weight W. As the power or small weight falls, therefore, the resistance, W, is raised with the multiplied force of three levers acting on each other.

68. "In respect to the force to be gained by such a machine, suppose the number of teeth on the axle of the wheel A to be six times less than the number of those on the circumference of the wheel, B, then B would only turn round once, while A turned six times. And in like manner, if the number of teeth on the circumference of D be six times greater than those on the axle of B, then D would turn once, while B turned six times. Thus, six revolutions of A would make B revolve once, and six revolutions of B would make D revolve once. Therefore, A makes thirty-six revolutions, while D makes only one. The diameter of the wheel A being three times the diameter of the axle of the wheel D, and its velocity of motion being 36 to 1, 3 times 36 will give the weight which a power of 1 pound at P would raise at W. Thus, 36×3=108. One pound at P would therefore balance 108 pounds at W.

69. *No machine creates force.*—" If the student has attended closely to what has been said on mechanics, he will now be prepared to understand that no machine, however simple or complex it may be, can *create* the least degree of force. It is true that one man with a machine may apply a force which a hundred could not exert with their hands, but then it would take him a hundred times as long. Suppose there are twenty blocks of stone to be moved a hundred feet; perhaps twenty men, by taking each a block, would move them all in a minute. One man, with a capstan, we will sup-

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68. What weight will one pound at P balance at W?—69. Is there *any actual power* gained by the use of machinery? Suppose 20 men to *move 20 stones to* a certain distance with their hands, and one man to move *them back to the* same place with a capstan, which perform the mos *actual labour?* *Why?* Why, then, is machinery a convenience?

pose, may move them all at once; but this man, with his lever, would have to make one revolution for every foot he drew the whole load towards him, and therefore to make one hundred revolutions to perform the whole work. It would also take him twenty times as long to do it as it took the twenty men. His task, indeed, would be more than twenty times harder than that performed by the twenty men, for, in addition to moving the stone, he would have the friction of the machinery to overcome, which commonly amounts to nearly one-third of the force employed. Hence there would be an actual loss of power by the use of the capstan, though it might be a convenience for the one man to do his work by its means, rather than to call in nineteen of his neighbours to assist him.

III. THE PULLEY.

70. The pulley consists of a solid wheel, called a *sheave*, fixed in a frame-work or *block*, and turning on its axis; a groove is formed round its circumference, over which a cord may pass. The several parts, taken together, are sometimes called the block, sometimes simply the pulley. Pulleys are of two kinds, the *fixed*, and the *moveable*. The fixed pulley, Fig. 37, revolves about its axis without changing its place; in this kind of pulley, the power and the weight, or resistance to be overcome, are both applied in directions which are

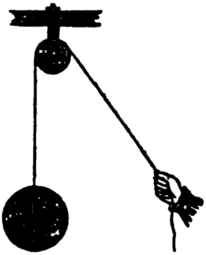

Fig. 37.

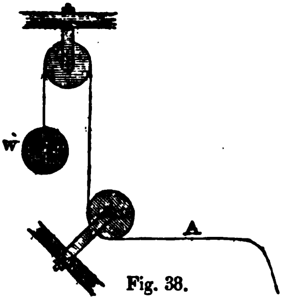

Fig. 38.

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70. Of what parts is a pulley composed? What is the character of the fixed pulley? In what directions do the power and the weight act *in the fixed pulley?* In what direction does the weight act in the move*able pulley?* State one of the most obvious advantages of the pulley?

tangents to the circumference of the pulley. In the moveable pulley, the weight or resistance is applied at the centre, or in a direction passing through the centre or axis of the pulley. One of the most obvious advantages of the pulley is, its enabling men to exert their own power in places where they cannot go themselves. Thus, by means of a rope and wheel, a man can stand on the deck of a ship, and hoist a weight to the top-mast.

71. "By means of two fixed pulleys, a weight may be raised upward, while the power moves in a horizontal direction. The weight will also rise vertically through the same space that the rope is drawn horizontally. Fig. 38 represents two fixed pulleys, as they are arranged for such a purpose. In the erection of a lofty edifice, suppose the upper pulley to be suspended to some part of the building; then a horse, pulling at the rope A, would raise the weight, W, vertically, as far as he might go horizontally.

72. "In the use of the single *fixed* pulley, there can be no mechanical advantage, since the weight rises as fast as the power descends. This is obvious by Fig. 39, where it is also apparent that the power and weight must be exactly equal, to balance each other. In the single *moveable* pulley, Fig. 39, the same rope passes from the fixed point, A, to the power, P. It is evident, here, that the weight is supported equally by the two parts of the string between which it hangs. Therefore, if we call the weight, W, ten pounds, five pounds will be supported by one string, and five by the other. The power, then, will support twice its own weight, so that a person pulling with a force of five pounds at P, will raise ten pounds at W. The mechanical force, therefore, in respect to the power, is as two to one." It will be observed, by reference to the figure, that the *moveable* pulley, besides its motion round its axis, has also a progressive motion.

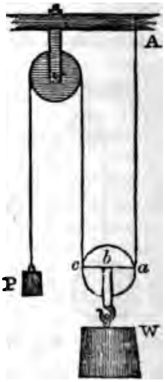

Fig. 39.

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71. How must two fixed pulleys be placed, to raise a weight vertically, as far as the power goes horizontally?—72. Is there any mechanical advantage in the fixed pulley? What weight at P, Fig. 39, will balance ten pounds at W? Show how the moveable pulley acts like a lever of the third kind.

The weight, W, hangs from the axis of the pulley, whilst the string which passes round it is secured at one end, and is acted upon at the other by the power P. Whether the string run parallel on each side of the pulley, or the power act vertically upward, in either case the pulley acts on the principle of a lever of the third kind, (§ 60,) whose arms are to each other, as 1 to 2. To illustrate this identity of action, let *c a* be the axis of the pulley; then, *c* is the fulcrum, *b* the point of the lever on which the weight acts, and *a* that on which the power acts; therefore the distance, *c b*, of the weight from the fulcrum is equal to the radius, or 1, and the distance, *c a*, of the power is equal to the diameter, or 2. The statical momentum, therefore, requires a force which shall be equal to half the weight, or, in other words, the *moveable pulley effects a saving equal to half the power.*

73. "In the foregoing example, it is supposed there are only two ropes, each of which bears an equal part of the weight. If the number of ropes be increased, the weight may be increased with the same power; or the power may be diminished in proportion as the number of ropes is increased. In Fig. 40, the number of ropes sustaining the weight is four, and therefore, the weight may be four times as great as the power. This principle must be evident, since it is plain that each rope sustains an equal part of the weight. The weight may therefore be considered as divided into four parts, and each part sustained by one rope."

74. A *system of pulleys* is a number of pulleys, either all moveable, or both moveable and fixed, acting in concert. A system of pulleys acts on the same principle as a compound lever. But the mechanical efficacy of a system of pulleys is derived entirely from the division of the weight among the strings employed in suspending it. "In Fig. 41, a system of pulleys is represented, in which the weight is sixteen times the power. The tension of the rope, D, E, is evidently equal to the power, P, because it sustains it; D being a moveable pulley, must sustain a weight equal to twice the power; but the weight which it sustains is the tension of the second rope,

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73. Suppose the number of ropes be increased, and the weight increased, must the power be increased also? Suppose the weight, Fig. 40, to be 32 pounds, what will each rope bear?—74. What is meant by *a system of pulleys?* What does the mechanical efficacy of a system of *pulleys depend on?*

D, C. Hence the tension of the second rope is twice that of the first, and, in like manner, the tension of the third rope is twice that of the second, and so on, the weight being equal to twice the tension of the last rope.

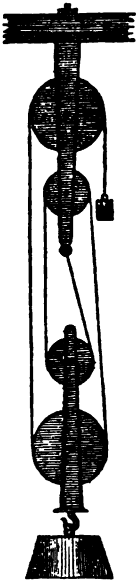

Fig. 40.

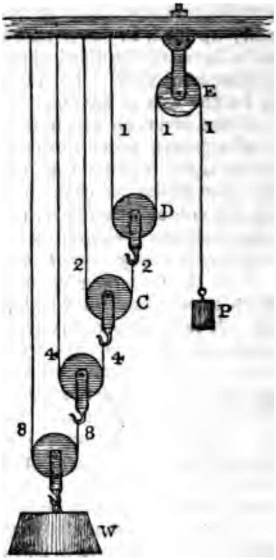

Fig. 41.

75. "Suppose the weight, W, to be sixteen pounds, then the two ropes, 8 and 8, would sustain just 8 pounds each, this being the whole weight divided equally between them. The next two ropes, 4 and 4, would evidently sustain but half this whole weight, because the other half is already sustained by a rope, fixed at its upper end. The next two ropes sustain but half of 4, for the same reason; and the next pair, 1 and 1,

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75. Explain Fig. 41, and show what part of the weight each rope *sustains, and why* 1 *pound* at P will balance 16 pounds at W. Explain the *reason why each additional* rope and pulley will double the effect of the *whole?*

for the same reason, will sustain only half of 2. Lastly, the power P, will balance two pounds, because it sustains but half this weight, the other half being sustained by the same rope, fixed at its upper end. It is evident that in this system each rope and pulley which is added will double the effect of the whole. Thus, by adding another rope and pulley beyond eight, the weight W might be 32 pounds, instead of 16, and still be balanced by the same power.

76. "In our calculations of the effects of pulleys, we have allowed nothing for the weight of the pulleys themselves, or for the friction of the ropes. In practice, however, it will be found, that nearly one-third must be allowed for friction, and that the power, therefore, to actually raise the weight, must be about one-third greater than has been allowed.

IV. THE INCLINED PLANE.

77. "The fourth simple mechanical power is the *inclined plane*. This power consists of a plain smooth surface, which is inclined towards or from the earth. It is represented by Fig. 42, where from A to B is the *inclined plane;* the line from D to A is its *height*, and that from B to D its *base*. A board, with one end on the ground, and the other end resting on a block, becomes an inclined plane. This machine, being both useful and easily constructed, is in very general use, especially where heavy bodies are to be raised only to a small height. Thus, a man, by means of an inclined plane, which he can readily construct with a board, or couple of bars, can raise a load into his wagon which ten men could not lift with their hands.

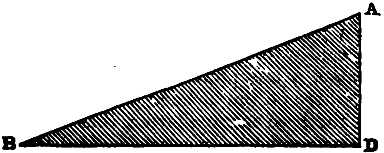

Fig. 42.

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76. In compound machines, how much of the power must be allowed *for the friction?*—77. What is an inclined plane? On what occasions *is this power* chiefly used? Suppose a man wants to load a barrel of cide *into his* wagon, how does he make an inclined plane for this purpose?

78. "The power required to force a given weight up an inclined plane is in a certain proportion to its height, and the length of its base, or, in other words, the force must be in proportion to the rapidity of its inclination. The power P, Fig. 43, pulling a weight up the inclined plane from C to D, only raises it in a perpendicular direction from E to D, by acting along the whole length of the plane. If the plane be twice as long as it is high, that is, if the line from C to D be double the length of that from E to D, then one pound at P will balance two pounds any where between D and C. It is evident, by a glance at this figure, that were the base, that is, the line from E to C, lengthened, the height from E to D being the same, a less power at P would balance an equal weight any where on the inclined plane; and so, on the contrary, were the base made shorter, that is, the plane more steep, the power must be increased in proportion.

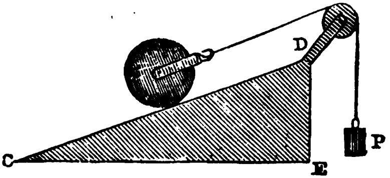

Fig. 43.

79. "Suppose two inclined planes, Fig. 44, of the same height, with bases of different lengths; then the weight and power will be to each other as the length of the planes. If the length from A to B is two feet, and that from B to C one

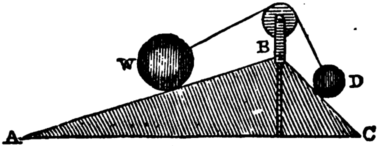

Fig. 44.

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78. To roll a given weight up an inclined plane, to what must the force be proportioned? Explain Fig. 43.—79. *If the length of the long plane, Fig. 44, be double that of the short one, what must be the proportion between the power and the weight?*

foot, then two pounds at D will balance four pounds at W, and so in this proportion, whether the planes be longer or shorter.

80. "The same principle, with respect to the vertical velocities of the weight and power, applies to the inclined plane, in common with the other mechanical powers. Suppose the inclined plane, Fig. 45, to be two feet from A to B, and one foot from C to B, then, as we have already seen by Fig. 43, a power of one pound at P would balance a weight of two pounds at W. Now, in the fall of the power to draw up the weight, it is obvious that its vertical descent must be just twice the vertical ascent of the weight; for the power must fall down the distance from A to B to draw the weight that distance; but the vertical height to which the weight W is raised, is only from C to B. Thus, the power, being two pounds, must fall two feet to raise the weight, four pounds, one foot; and thus the power and weight, multiplied by the several velocities, are equal.

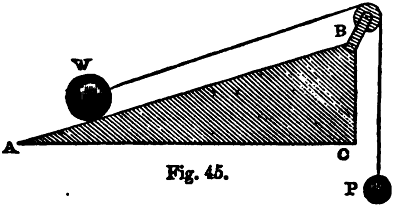

Fig. 45.

81. "When the power of an inclined plane is considered as a machine, it must therefore be estimated by the proportion which the length bears to the height; the power being increased in proportion as the elevation of the plane is diminished. Hilly roads may be regarded as inclined planes, and loads drawn upon them in carriages, considered in reference to the powers which impel them, and subject to all the conditions which we have stated, with respect to inclined planes. The power required to draw a load up a hill, is in proportion to the length and elevation of the inclined plane. On a road, perfectly horizontal, if the power is sufficient to overcome the friction, and the resistance of the atmosphere, the carri-

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80. What is said of the application of the law of vertical velocities to *the inclined plane?* Explain Fig. 45, and show why the power must *fall twice as far* as the weight rises.—81. How must the power of an *inclined plane be estimated?* Illustrate this with reference to hilly road

age will move. But if the road rise one foot in fifteen, besides these impediments, the moving power will have to lift one fifteenth part of the load. If two roads rise, one at the rate of a foot in fifteen feet, and another at the rate of a foot in twenty, then the same power that would move a given weight fifteen feet on the one, would move it twenty feet on the other, in the same time. In the building of roads, therefore, both speed and power are very often sacrificed to want of judgment, or ignorance of these laws. A road, as every traveller knows, is often continued directly over a hill, when half the power, with the increase of speed, on a level road around it, would gain the same distance in half the time.

V. THE WEDGE.

82. "The next simple mechanical power is the *wedge*. This instrument may be considered as two inclined planes, placed base to base. It is much employed for the purpose of splitting or dividing solid bodies, such as wood and stone. Fig. 46 represents such a wedge as is usually employed in cleaving timber. This instrument is also used in raising ships, and preparing them to launch, and for a variety of other purposes. Nails, awls, needles, and many cutting instruments, act on the principle of this machine. There is much difficulty in estimating the power of the wedge, since this depends on the force or the number of blows given it, together with the obliquity of its sides. A wedge of great obliquity would require hard blows to drive it forward, for the same reason that a plane much inclined requires much force to roll a heavy body up it. But were the obliquity of the wedge, and the force of each blow, given, still it would be difficult to ascertain the exact power of the wedge in ordinary cases, for, in the splitting of timber and stone, for instance, the divided parts act as levers, and thus greatly increase the power of the wedge. Thus, in a log of wood six feet long, when split one half of its length, the other

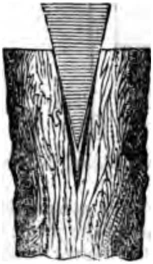

Fig. 46.

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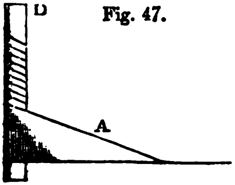
82. On what principle does the wedge act? In what case is this power *useful? What common* instruments act on the principle of the wedge? *What difficulty is there* in estimating the power of the wedge?

half is divided with ease, because the two parts act as levers, the lengths of which constantly increase as the cleft extends from the wedge.

VI. THE SCREW.

83. The *screw* is the sixth and last simple mechanical power. It may be considered as a modification of the inclined plane, or as a winding wedge. It is, in fact, an inclined plane running spirally round a spindle; or it may be described, in other words, as formed by winding a right-angled triangle about a cylinder, so that the longer of the two sides containing the right angle shall be perpendicular to the cylinder, as will be seen in Fig. 47. Suppose A to be a piece of paper cut into the form of an inclined plane, or of a right-angled triangle, and rolled round the cylinder of wood D, the edge of the former figure, or the hypothenuse of the latter, would form the spiral line, called the *thread* or *worm* of the screw. Every part of this line which passes once round the periphery of the cylinder, is called a *spire* of the thread or worm, and each such part requires an equal portion of the inclined plane or triangle. The distance of one spire from the next coincides with the height of the corresponding portions of the plane or triangle, and is called the *breadth* of the screw. If the finger be placed between two spires of a screw, and the screw be turned round once, the finger will be raised upward to a distance equal to that of the two spires apart. In this manner, the finger is raised up the inclined plane as it runs round the cylinder.

Fig. 47.



84. When the screw line consists of one continuous ele-

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83. On what principle does the screw act? How is it shown that the screw is a modification of the inclined plane, and of a right-angled triangle? Explain Fig. 47. What is meant by the thread, the spire, and the breadth of the screw?—84. What is meant by a male, and what by a female screw? By what other name is the latter designated? Explain Fig. 48. Which is the screw, and which the nut? Which way must the screw be turned to make it advance through the nut? How does the screw, Fig. 48, differ from Fig. 49? Is the screw ever *used* as a simple machine? By what other simple power is it moved? *What* two simple mechanical powers are concerned in the force of t *screw?*

vation, as above described, the cylinder forms *a male screw.* But its power may be transmitted and employed by means of another screw, having a spiral groove running through it, which exactly fits the thread of the former; this is called the *nut* or *female* screw. The combination of these two parts constitutes the mechanical power known as the screw. If the nut is fixed, the (male) screw, on being turned round, advances forward; but if the (male) screw is fixed, the nut, when turned, advances along its thread. Fig. 48 represents the former kind of screw, being such as is commonly used in pressing paper, and other substances. The nut N, through which the screw passes, answers also for one of the beams of the press. If the screw be turned to the right, it will advance downwards, while the nut stands still. A screw of the second kind is represented by Fig. 49. In this, the screw is fixed, while the nut, N, by being turned by the lever, L, from right to left, will advance down the screw. In practice, the screw is never used as a simple mechanical machine; the power being always applied by means of a lever, passing through the head of the screw, as in Fig. 48, or into the nut, as in Fig. 49. The screw, therefore, acts with the combined power of the inclined plane and the lever, and its force is such as to be limited only by the strength of the materials of which it is made. In investigating the effects of this machine, we *must, therefore,* take into account both these simple *mechanical powers,* so that the screw now becomes really *a compound engine.*

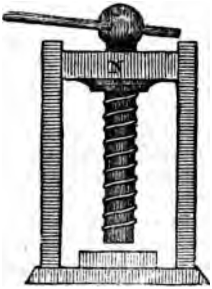

Fig. 48.

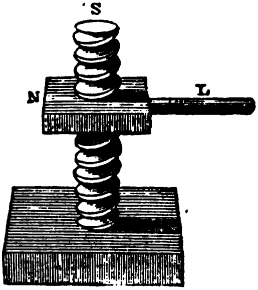

Fig. 49.

85. "In the inclined plane, we have already seen, that the less it is inclined, the more easy is the ascent up it. In applying the same principle to the screw, it is obvious that the greater the distance of the threads from each other, the more rapid the inclination, and, consequently, the greater must be the power to turn it, under a given weight. On the contrary, if the thread incline downwards but slightly, it will turn with less power, for the same reason that a man can roll a heavy weight up a plane but little inclined. Therefore, the finer the screw, or the nearer the threads to each other, the greater will be the pressure under a given power. Let us suppose two screws, the one having the threads one inch apart, and the other half an inch apart; then the force which the first screw will give with the same power at the lever will be only half that given by the second. The second screw must be turned twice as many times round as the first, to go through the same space; but what is lost in velocity is gained in power. At the lever of the first, two men would raise a given weight to a given height by making one revolution; while at the lever of the second, one man would raise the same weight to the same height, by making two revolutions.

86. "*Perpetual screw.*—The force of the screw is sometimes employed to turn a wheel, by acting on its teeth. In this case it is called the *perpetual screw.* Fig. 50 represents such a machine. It is apparent, that by turning the crank C, the wheel will revolve, for the thread of the screw passes between the cogs of the wheel. By means of an axle, through the centre of this wheel, like the common wheel and axle, this becomes an exceedingly powerful machine, but, like all other contrivances for obtaining great power, its effective motion is exceedingly slow. It has, however, some disadvan-

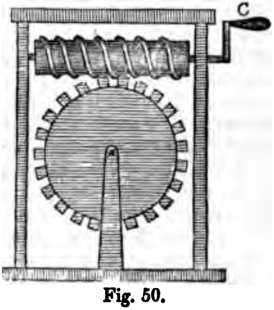

Fig. 50.

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85. Why does the nearness of the threads make a difference in the force of the screw? Suppose one screw, with its threads one inch apart, and another half an inch apart, what will be their difference in force?—*86. What is the screw called, when it is employed to turn a wheel? What is the object of this machine for raising weights?*

tages, and particularly the great friction between the thread of the screw and the teeth of the wheel, which prevents it from being generally employed to raise weights.

87. "*All the mechanical powers resolved into three.*—We have now enumerated and described all the mechanical powers usually denominated simple. They are six in number, namely, the Lever, Wheel and Axle, Pulley, Wedge, Inclined Plane, and Screw. In respect to the principle on which they act, they may be resolved into three simple powers, namely, the lever, the inclined plane, and the pulley; for it has been shown that the wheel and axle is only another form of the lever, and that the screw is but a modification of the inclined plane." The principles developed by the mechanical powers are reduced by Peschel to a still greater simplicity. It will be found, he says, that all the laws which regulate equilibrium in each, either depend immediately on those which are established with regard to the lever, or may be deduced from the principal laws of motive powers. The *lever* may, therefore, be regarded as the *fundamental machine;* and as all compound machines are merely constructions of the simple ones, it follows that *the lever furnishes the fundamental law for the entire theory of machinery.*

88. "*Use of machinery.*—Notwithstanding the vast deal of time and ingenuity which men have spent on the construction of machinery, and in attempting to multiply their powers, there has, as yet, been none produced, in which the power was not obtained at the expense of velocity, or velocity at the expense of power; and, therefore, no actual force is ever generated by machinery. Suppose a man able to raise a weight by means of a compound pulley of ten ropes, which it would take ten men to raise, by one rope without pulleys. If the weight is to be raised a yard, the ten men by pulling their rope a yard will do the work. But the man with the pulleys must draw his rope ten yards to raise the weight one yard, and in addition to this, he has to overcome the friction of the ten pulleys, making about one-third more actual labour than was employed by the ten men.

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87. How may all the mechanical powers be resolved into three simple *powers?*—88. Is any actual force generated by machinery? Can great *velocity and great force* be produced by the same machinery? Why not? *Which perform the greater* labour, ten men who lift a weight with their *hands, or one man* who does the same with ten pulleys? Why?

89. "But notwithstanding these inconveniences, the use of machinery is of vast importance to the world. 1. On board of a ship, a few men will raise an anchor with a capstan, which it would take ten or twenty times the same number to raise without it, and thus the expense of shipping men expressly for this purpose is saved. 2. One man with a lever may move a stone which it would take twenty men to move without it, and though it should take him twenty times as long, he would still be the gainer, since it would be more convenient, and less expensive, for him to do the work himself, than to employ twenty others to do it for him. 3. When men employ the natural elements as a power to overcome resistance by means of machinery, there is a vast saving of animal labour. Thus mills, and all kinds of engines, which are kept in motion by the power of water, or wind, or steam, save animal labour equal to the power it takes to keep them in motion."

CHAP. III.

OF HYDROSTATICS.

90. HYDROSTATICS is that branch of mechanics which treats of the weight, pressure, and equilibrium of fluids, when in a state of rest; and of these properties of solids, when immersed in fluids. A *fluid* is a collection of material particles, which are easily moved among themselves. The fluids which nature presents to us, approach more or less to this condition, and they are commonly distinguished into the elastic, and the inelastic. 1. *Elastic* fluids are those which are capable of being compressed into a smaller bulk, and of recovering their dimensions when the compressing force is removed; of this kind are atmospheric air and all the gases. Some *gases* may

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89. Enumerate some important uses of machinery.—90. What branch of mechanics is denoted by the term Hydrostatics? Define a fluid. Into what two classes are fluids distinguished? What is an elastic fluid? What fluids come under this denomination? Give an instance of a gas capable of assuming the liquid, and even the solid form. How do *vapours differ from air and gases?* What bodies are generally considered *inelastic?*

be compressed to such an extent, as to assume the form of liquids and solids: that is, from the condition of being invisible, they may be rendered perceptible to the eye, and appreciable by the touch, as in the case of carbonic acid gas. *Vapours* differ from air and the gases, by losing the form of elastic fluids and returning to the state of liquids, when compressed to a certain degree, or when their temperature is sufficiently reduced. This remark must, however, be made with certain restrictions, several of the gases having been condensed into liquids by Mr Faraday, under pressures varying from two to fifty atmospheres, and at temperatures ranging from 45° to 60°. 2. *Inelastic* fluids are those formerly supposed to be incompressible, and among these were ranged water, mercury, alcohol, and liquids generally. But the term is incorrect: the phenomenon of the transmission of sound through water and other liquids, had long ago indicated that they were capable of being compressed.

EQUAL PRESSURE OF WATER.

91. "The particles of water, and other fluids, when confined, press on the vessel which confines them, in all directions, both upwards, downwards, and sideways. From this property of fluids, together with their weight, or gravity, very unexpected and surprising effects are produced. The effect of this property, which we shall first examine, is, that a quantity of water, however small, will balance another quantity however large. Fig. 51 represents a common coffee-pot, supposed to be filled up to the dotted line A, with a decoction of coffee, or any other liquid. The coffee, we know, stands exactly at the same height, both in the body of the pot, and in its spout. Therefore, the small quantity in the spout balances the large quantity in the pot, or presses with the same force downwards, as that in the body of the pot presses upwards. This is obviously true, otherwise the large quantity would sink below the dotted line, while that in the spout would rise above it, and run over.

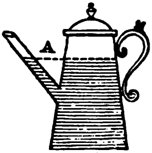

Fig. 51.

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91. When water is confined, in what direction does it press? How *does the experiment* with the coffee-pot show that a small quantity of *liquid will balance* a large one?

92. "The same principle is more strikingly illustrated by Fig. 52. Suppose the cistern A to be capable of holding one hundred gallons, and into its bottom there be fitted the tube B, bent, as seen in the figure, and capable of containing one gallon. The top of the cistern, and that of the tube, being open, pour water into the tube at C, and it will rise up through the perpendicular bend into the cistern, and if the process be continued, the cistern will be filled by pouring water into the tube. Now, it is plain, that the gallon of water in the tube presses against the hundred gallons in the cistern, with a force equal to the pressure of the hundred gallons, otherwise that in the tube would be forced upwards higher than that in the cistern, whereas we find that the surfaces of both stand exactly at the same height.

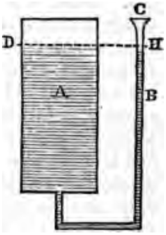

Fig. 52.

93. "From these experiments we learn, '*that the pressure of a fluid is not in proportion to its quantity, but to its height. and that a large quantity of water, in an open vessel, presses down with no more force than a small quantity of the same height.*'

94. "Thus far we have considered the fluid as acting only in vessels with open mouths, and therefore at liberty to seek its balance, or equilibrium, by its own gravity. Its pressure, we have seen, is in proportion to its height, and not to its bulk. Now, by other experiments, it is ascertained, *that the pressure of a liquid is in proportion to its height, and its area at the base.* Suppose a vessel, ten feet high, and two feet in diameter, such as is represented at A, Fig. 53, to be filled with water; there would be a certain amount of pressure, say at C, near the

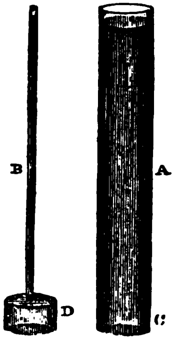

Fig. 53.

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92. Explain Fig. 52, and show how the pressure in the tube is equal to the pressure in the cistern.—93. What conclusion, or general truth is to be drawn from these experiments?—94. Is the force of water in proportion to its height, or its quantity? How is a small quantity of water shown to press equal to a large quantity by Fig. 53? Explain the reason why the pressure is as great at D as at C.

bottom. Let D represent another vessel, of the same diameter at the bottom, but only a foot high, and closed at the top. Now, if a small tube, say the fourth of an inch in diameter, be inserted into the cover of the vessel D, and this tube be carried to the height of the vessel A, and then the vessel and tube be filled with water, the pressure on the bottoms and sides of both vessels to the same height will be equal, and jets of water starting from D and C, will have exactly the same force. This might at first seem improbable, but to convince ourselves of its truth, we have only to consider, that any impression made on one portion of the confined fluid in the vessel D, is instantly communicated to the whole mass. Therefore, the water in the tube B presses with the same force on every other portion of the water in D, as it does on that small portion over which it stands.

95. "This principle is illustrated in a very striking manner, by the experiment, which has often been made, of bursting the strongest wine-cask with a few ounces of water. 1. Let A, Fig. 54, be a strong cask, already filled with water, and suppose the tube B, thirty feet high, to be screwed, water tight, into its head. When water is poured into the tube, so as to fill it gradually, the cask will show increasing signs of pressure, by emitting the water through the pores of the wood, and between the joints; and, finally, as the tube is filled, the cask will burst asunder. 2. The same apparatus will serve to illustrate the upward pressure of water; for if a small stop-cock be fitted to the upper head, on turning this, when the tube is filled, a jet of water will spirt up with a force, and to a height, that will astonish all who never before saw such an experiment. 3. In theory, the water will spout to the same height with that which gives the pressure, but in practice, it is found to fall short, in the following proportions: If the tube be twenty feet high, and the orifice for the jet half an inch in diameter, the water will

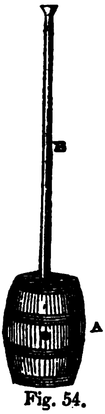

Fig. 54.

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95. How is the same principle illustrated by Fig. 54? How is the *upward pressure of* water illustrated by the same apparatus? Under the *pressure of a column of* water twenty feet high, what will be the height *of the jet? Under* a pressure of a hundred feet, how will it rise?

spout nearly nineteen feet. If the tube be fifty feet high, the jet will rise upwards of forty feet; and if a hundred feet, it will rise above eighty feet. It is understood, in every case, that the tubes are to be kept full of water. The height of these jets shows the astonishing effects that a small quantity of fluid produces when pressing from a perpendicular elevation.

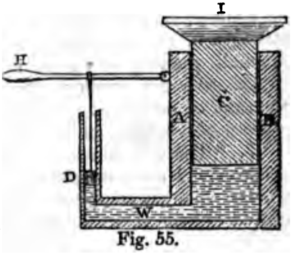

Fig. 55.

96. "*Hydrostatic press.*—This property of water was applied by Mr Bramah to the construction of his *hydrostatic* press. But instead of a high tube of water, which in most cases could not be so readily obtained, he substituted a strong forcing pump, and instead of the leather bellows, a metallic pump-barrel and piston. 1. This arrangement will be understood by Fig. 55, where the pump-barrel, A, B, is represented as divided lengthwise, in order to show the inside. The piston, C, is fitted so accurately to the barrel, as to work up and down water-tight; both barrel and piston being made of iron. The thing to be broken, or pressed, is laid on the flat surface, I, there being above this a strong frame to meet the pressure, not shown in the figure. The small forcing pump, of which D is the piston, and H the lever by which it is worked, is also made of iron. 2. Now, suppose the space between the small piston and the large one, at W, to be filled with water, then, on forcing down the small piston, D, there will be a pressure against the large piston, C, the whole force of which will be in proportion as the aperture in which C works, is greater than that in which D works. If the piston, D, is half an inch in diameter, and the piston, C, one foot in diameter, then the pressure on C will be 576 times greater than that on D.

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96. Explain Fig. 55. Where is the piston? Which is the pump-barrel, in which it works? In the hydrostatic press, what is the proportion between the pressure given by the small piston, and the force exerted on the large one? What is the estimated force which a man could give by means of one of these engines? If the pressure of two tons be made on a piston of a quarter of an inch in diameter, what will be the force transmitted to the other piston of three feet in diameter?

Therefore, if we suppose the pressure of the small piston to be one ton, the large piston will be forced up against any resistance with a pressure equal to the weight of 576 tons. It would be easy for a single man to give the pressure of a ton at D, by means of the lever, and, therefore, a man, with this engine, would be able to exert a force equal to the weight of near 600 tons. 3. It is evident, that the force to be obtained by this principle, can only be limited by the strength of the materials of which the engine is made. Thus, if a pressure of two tons be given to a piston, the diameter of which is only a quarter of an inch, the force transmitted to the other piston, if three feet in diameter, would be upwards of 40,000 tons; but such a force is much too great for the strength of any material with which we are acquainted. 4. A small quantity of water, extending to a great elevation, would give the pressure above described, it being only for the sake of convenience that the forcing pump is employed, instead of a column of water.

97. "There is no doubt, but in the operations of nature, great effects are sometimes produced among mountains, by a small quantity of water finding its way to a reservoir in the crevices of the rocks far beneath. Suppose, in the interior of a mountain, Fig. 56, there should be a space of ten yards square, and an inch deep, filled with water, and closed up on all sides; and suppose that, in the course of time, a small fissure, no more than an inch in diameter, should be opened

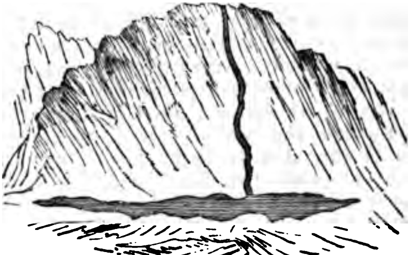

Fig. 56.

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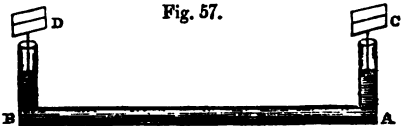
97. *What is said of the* pressure of water in the crevices of mountains, *and the consequences?*

by the water, from the height of two hundred feet above, down to this little reservoir. The consequence might be, that the side of the mountain would burst asunder, for the pressure, under the circumstances supposed, would be equal to the weight of five thousand tons.

98. *Water level.*—" We have seen that in whatever situation water is placed, it always tends to seek a *level*. Thus, if several vessels, communicating with each other, be filled with water, the fluid will be at the same height in all, and the level will be indicated by a straight line drawn through all the vessels. It is on the principle of this tendency that the little instrument called the *water level* has been constructed.

Fig. 57.



The form of this instrument is represented by Fig. 57. It consists of a tube, A, B, with its two ends turned at right angles, and left open. Into one of the ends is poured water or mercury, until the fluid rises a little in the angles of the tube. On the surface of the fluid at each end are then placed small floats, carrying upright frames, across which are drawn small wires or hairs, as seen at C and D. These hairs are called the *sights*, and are across the line of the tube. It is obvious that this instrument will always indicate a level when the floats are at the same height in respect to each other, and not in respect to their comparative heights in the ends of the tube, for if one end of the instrument be held lower than the other, still the floats must always be at the same height. To use this level, therefore, we have only to bring the two sights so that one will range with the other; and on placing the eye at C, and looking towards D, this is determined in a moment. This level is indispensable in the construction of canals and aqueducts, since the engineer depends entirely on it to ascertain whether the water can be carried over a given hill or mountain.

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98. On what principle is the water level constructed? Describe the manner in which the level with *sights* is used, and the reason why the floats will always be at the same height. What is the use of the *level?*

99. "The common *spirit level* consists of a glass tube, Fig. 58, filled with spirit of wine, excepting a small space in which there is left a bubble of air. This bubble, when the instrument is laid on a level surface, will be exactly in the middle of the tube, and therefore to adjust a level, it is only necessary to bring the bubble to this position. The glass tube is enclosed in a brass case, which is cut out on the upper side, so that the bubble may be seen, as represented in the figure. This instrument is employed by builders to level their work, and is highly convenient for that purpose, since it is only necessary to lay it on a beam to try its level.

Fig. 58.

SPECIFIC GRAVITY.

100. "If a tumbler be filled with water to the brim, and an egg, or any other heavy solid, be dropped into it, a quantity of the fluid, exactly equal to the size of the egg, or other solid, will be displaced, and will flow over the side of the vessel. Bodies which sink in water, therefore, displace a quantity of the fluid equal to their own bulks. Now, it is found, by experiment, that when any solid substance sinks in water, it loses, while in the fluid, a portion of its weight, just equal to the weight of the bulk of water which it displaces. This is readily made evident by experiment. Take a piece of ivory, or any other substance that will sink in water, and weigh it accurately in the usual manner; then suspend it by a thread, or hair, in the empty cup A, Fig. 59, and then balance it, as shown in the figure. Now pour water into the cup, and it will be found that the suspended body will lose a part of its weight, so that a certain number of grains must be taken from the opposite scale, in order to make the scales balance as before the water was

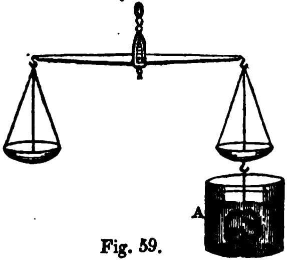

Fig. 59.

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99. Describe the common spirit level, and the method of using it.—*100. When a solid is* weighed in water, why does it lose a part of its *weight?*

poured in. The number of grains taken from the opposite scale is just the weight of a quantity of water equal to the bulk of the body so suspended.

101. "It is on the principle that bodies weigh less in the water than they do when weighed out of it, or in the air, that water becomes the means of ascertaining their specific gravities, for it is by comparing the weight of a body in the water, with what it weighs out of it, that its specific gravity is determined. Thus, suppose a cubic inch of gold weighs nineteen ounces, and on being weighed in water, weighs only eighteen ounces, or loses a nineteenth part of its weight, it will prove that gold, bulk for bulk, is nineteen times heavier than water, and thus nineteen would be the specific gravity of gold. And so if a cube of copper weigh nine ounces in the air, and only eight ounces in the water, then copper, bulk for bulk, is nine times as heavy as water, and therefore has a specific gravity of nine. If the body weigh less, bulk for bulk, than water, it is obvious that it will not sink in it, and therefore weights must be added to the lighter body to ascertain how much less it weighs than water. The specific gravity of a body, then, is merely its weight, compared with the same bulk of water; and water is thus made the standard by which the weights of all other bodies are compared.

THE SYPHON.

102. "Take a tube, bent like the letter U, and having filled it with water, place a finger on each end, and in this state plunge one of the ends into a vessel of water, so that the end in the water shall be a little the higher, then remove the fingers, and the liquid will flow out, and continue to do so, until the vessel is exhausted. A tube acting in this manner, is called a *syphon*, and is represented by Fig. 60. The reason why the water flows from the end of the tube A, and, consequently, ascends through the

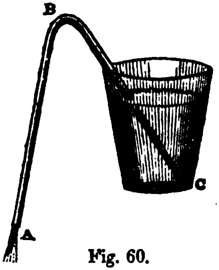

Fig. 60.

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101. How much less will a cubic inch of any substance weigh in water than in air? How is it proved, by Fig. 59, that a body weighs less in water than in air? What is the specific gravity of a body?—102. In what *manner* is a syphon made? Explain the reason why the water *ascends through* one leg of the syphon, and descends through the other.

other part, is, that there is a greater weight of the fluid from B to A, than from C to B, because the perpendicular height from B to A is the greater. The weight of the water from B to A falling downwards, by its gravity, tends to form a vacuum, or void space, in that leg of the tube, but the pressure of the atmosphere on the water in the vessel, constantly forces the fluid up the other leg of the tube, to fill the void space, and thus the stream is continued so long as any water remains in the vessel."

103. From this account it is evident that the uninterrupted flow is owing to the unequal pressure of the columns of liquid in the two legs of the syphon. In both legs the upward pressure of the atmosphere is equally exerted: in the immersed leg, the pressure is transmitted by the liquid in the vessel; in the other leg, it acts immediately at the aperture. This pressure of the air is, in both cases, opposed by the weight of the liquid, and as the columns of liquid are of unequal length, the greater force of gravity of the larger column determines the pressure, that is, the flow of the liquid in this direction. The influence of the atmosphere, in producing this phenomenon, may be ascertained by inserting a syphon airtight into one of the openings of a double-mouthed bottle; so long as the other mouth remains open, the liquid will continue to flow; but, if this mouth be closed with a cork, the liquid will cease to escape. If the experiment be made under the receiver of an air-pump, the flow will cease when the air has been rarefied to a certain extent.

104. "*Intermitting springs.*—The action of the syphon depends upon the same principle as the action of the pump, namely, the pressure of the atmosphere, and therefore its explanation properly belongs to Pneumatics. It is introduced here merely for the purpose of illustrating the phenomena of intermitting springs; a subject which properly belongs to Pneumatics. Some springs, situated on the sides of mountains, flow for a while with great violence, and then cease entirely; after a time, they begin to flow again, and then suddenly stop, as before. These are called intermitting springs, and they owe their peculiarities to nothing more than

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103. Prove that the action of the syphon depends on atmospheric *pressure.* What is an intermittent spring?—104. How is the *phenomenon of the intermittent* spring explained? Explain Fig. 61, and shew *the reason why such* a spring will flow and cease alternately.

natural syphons, existing in the mountains from whence the water flows. Fig. 61 is the section of a mountain and spring, showing how the principle of the syphon operates to produce the effect described. Suppose there is a crevice, or hollow in the rock from A to B, and a narrow fissure leading from it, in the form of the syphon, B C. The water, from the rills F, E, filling the hollow up to the line A D, it will then discharge itself through the syphon, and continue to run until the water is exhausted down to the leg of the syphon B, when it will cease. Then the water from the rills continuing to run until the hollow is again filled up to the same line, the syphon again begins to act, and again discharges the contents of the reservoir as before; and thus the spring P, at one moment flows with great violence, and the next moment ceases entirely. The hollow above the line A D, is supposed not to be filled with the water at all, since the syphon begins to act whenever the fluid rises up to the bend D. During the dry seasons of the year, it is obvious that such a spring would cease to flow entirely, and would begin again only when the water from the mountain filled the cavity through the rills."

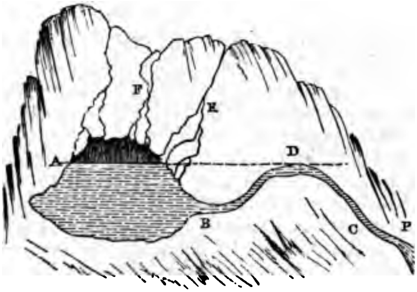

Fig. 61.

CHAP. IV.

OF HYDRAULICS.

105. "It has been stated, (§ 90,) that Hydrostatics is that branch of Natural Philosophy which treats of the weight, pressure, and equilibrium of fluids; Hydraulics has for its object the investigation of the laws which regulate fluids in motion. If the pupil has learned the principles on which the pressure and equilibrium of fluids depend, as explained under the former article, he will now be prepared to understand the laws which govern fluids when in motion. The pressure of water, downwards, is exactly in the same proportion to its height, as is the pressure of solids in the same direction. Suppose a vessel of three inches in diameter has a billet of wood set up in it, so as to touch only the bottom, and suppose the piece of wood to be three feet long, and to weigh nine pounds; then the pressure on the bottom of the vessel will be nine pounds. If another billet of wood be set on this, of the same dimensions, it will press on its top with the weight of nine pounds, and the pressure at the bottom will be 18 pounds, and if another billet be set on this, the pressure at the bottom will be 27 pounds, and so on, in this ratio, to any height the column is carried.

106. "Now, the pressure of fluids is exactly in the same proportion; and when confined in pipes, may be considered as one short column set on another, each of which increases the pressure of the lowest in proportion to its number and height. Thus, notwithstanding the lateral pressure of fluids, their downward pressure is as their heights. This fact will be found of importance in the investigation of the principles of certain hydraulic machines, and we have therefore endeavoured to impress it on the mind of the pupil by Fig. 62, where it will be seen, that if the pressure of three feet of

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105. How does the science of Hydrostatics differ from that of *Hydraulics?* *Does the downward pressure of water differ from the downward pressure of solids, in proportion?*—106. How is the downward *pressure of water illustrated?* Without reference to the lateral pressure, *in what proportion do fluids press downwards?*

water be equal to nine pounds on the bottom of the vessel, the pressure of twelve feet will be equal to thirty-six pounds.

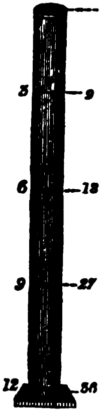

Fig. 62.

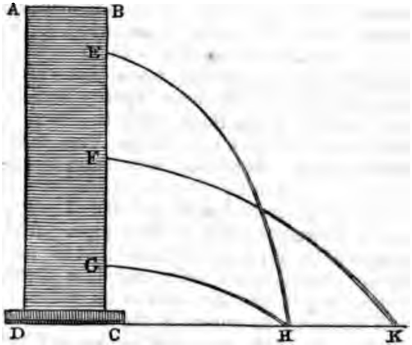

Fig. 63.

107. "The quantity of water which will be discharged from an orifice of a given size, will be in proportion to the height of the column of water above it, for the discharge will increase in velocity, in proportion to the pressure, and the pressure, we have already seen, will be in a fixed ratio to the height. If a vessel such as that represented in Fig. 63, be filled with water, and three apertures be made in its side at the points E, F, and G, the fluid will be thrown out in jets, and will fall towards the earth in the curved lines E, F, and G. The reason why these curves differ in shape, is, that the fluid is acted on by two forces, namely, the pressure of water above the jet, which produces its velocity forward, and the action of gravity which impels it downward. It therefore obeys the same laws that solids do when projected forward, and falls down in curved lines, the shapes of which depend on their relative velocities. The quantity of water discharged being in proportion to the pressure, that discharged from

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107. What will be the proportion of a fluid discharged from an orifice of a given size? Why do the lines described by the jets from the *vessel, Fig. 63,* differ in shape? What two forces act upon the fluid *as it is discharged,* and how do these forces produce a curved line?

each orifice will differ in quantity, according to the height of water above it.

108. "It is found, however, that the velocity with which a vessel discharges its contents, does not depend entirely on the pressure, but in part on the kind of orifice through which the liquid flows. It might be expected, for instance, that a tin vessel of a given capacity, with an orifice of, say, an inch in diameter, through its side, would part with its contents sooner than another of the same capacity and orifice, whose side was an inch or two thick, since the friction through the tin might be considered much less than that presented by the other orifice. But it has been found by experiment, that the tin vessel does not part with its contents so soon as another vessel, of the same height and size of orifice, from which the water flowed through a short pipe. And, on varying the length of these pipes, it is found that the most rapid discharge, other circumstances being equal, is through a pipe whose length is twice the diameter of its orifice. Such an aperture will discharge 82 quarts, in the same time that another vessel of tin, without the pipe, will discharge 62 quarts.

109. "This surprising difference is accounted for by supposing that the cross currents, made by the rushing of the water from different directions towards the orifice, mutually interfere with each other, by which the whole is broken, and thrown into confusion by the sharp edge of the tin, and hence the water issues in the form of spray, or of a screw, from such an orifice. A short pipe seems to correct this contention among opposing currents, and to smooth the passage of the whole, and hence we may observe, that from such a pipe, the stream is round and well defined.

110. "*Friction between solids and fluids.*—The rapidity with which water flows through pipes of the same diameter, is found to depend much on the nature of their internal surfaces. Thus a lead pipe, with a smooth aperture, under the

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108. Does the velocity with which a fluid is discharged depend entirely on the pressure? What circumstance besides pressure facilitates the discharge of water from an orifice? In a tube discharging water with the greatest velocity, what is the proportion between its diameter and its length?—109. What is the proportion between the quantity of fluid discharged through an orifice of tin, and through a short pipe?—110. Suppose a lead and a glass tube, of the same diameter, which will deliver the greatest quantity of liquid in the same time? Why will a glass tube deliver most? What is said of the sudden turnings of a tube, in retarding the motion of the fluid.

same circumstances, will convey much more water than one of wood, where the surface is rough, or beset with points. In pipes, even where the surface is as smooth as glass, there is still considerable friction, for in all cases the water is found to pass more rapidly in the middle of the stream than it does on the outside, where it rubs against the side of the tube. The sudden turns, or angles of a pipe, are also found to be a considerable obstacle to the rapid conveyance of the water, for such angles throw the fluid into eddies or currents, by which its velocity is arrested. In practice, therefore, sudden turns are generally avoided, and where it is necessary that the pipe should change its direction, it is done by means of as large a circle as convenient.

111. "Where it is proposed to convey a certain quantity of water to a considerable distance in pipes, there will be a great disappointment in respect to the quantity actually delivered, unless the engineer take into account the friction, and the turnings of the pipes, and make large allowances for these circumstances. If the quantity to be actually delivered ought to fill a two inch pipe, one of three inches will not be too great an allowance, if the water is to be conveyed to any considerable distance. In practice, it will be found that a pipe of two inches in diameter, one hundred feet long, will discharge about five times as much water as one of one inch in diameter of the same length, and under the same pressure. This difference is accounted for, by supposing that both tubes retard the motion of the fluid, by friction, at equal distance from their inner surfaces, and consequently, that the effect of this cause is much greater in proportion, in a small tube, than in a large one.

112. "The effect of friction in retarding the motion of fluids is perpetually illustrated in the flowing of rivers and brooks. On the side of a river, the water, especially where it is shallow, is nearly still, while in the midde of the stream it may run at the rate of five or six miles an hour. For the same reason, the water at the bottoms of rivers is much less rapid than at the surface. This is often proved by the oblique position of floating substances, which in still water

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111. How much more water will a two-inch tube of a hundred feet long discharge than a one-inch tube of the same length? How is this *difference accounted* for? 112. How do rivers shew the effect of friction *in retarding* the motion of their waters?

would assume a vertical direction. Thus, suppose the stick of wood, E, Fig. 64, to be loaded at one end with lead, of the same diameter as the wood, so as to make it stand upright in still water. In the current of a river, where the lower end nearly reaches the bottom, it will incline as in the figure, because the water is more rapid towards the surface than at the bottom, and hence the tendency of the upper end to move faster than the lower one, gives it an inclination forward.

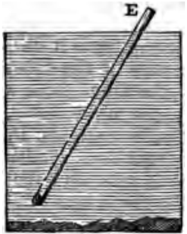

Fig. 64.

113. "*Archimedes's screw.*—One of the most curious, as well as ancient machines, is the *screw of Archimedes*, which was invented by the celebrated philosopher of that name, two hundred years before the Christian era, and then employed for raising water and draining land in Egypt. It consists of a large tube, Fig. 65, coiled round a shaft of wood to keep it in place, and give it support. Both ends of the tube are open, the lower one being dipped into the water to be raised, and the upper one discharging it in an intermitting stream. The shaft turns on a support at each end, that at the upper end being seen at A, the lower one being hid by the water. As the machine now stands, the lower

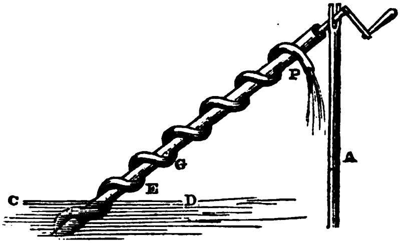

Fig. 65.

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113. Explain the screw of Archimedes, as represented in Fig. 65, *and show how* water is elevated by turning it. How may the principle *of Archimedes's* screw be readily illustrated?

bend of the screw is filled with water, since it is below the surface C, D. On turning it by the handle, from left to right, that part of the screw now filled with water will rise above the surface C, D, and the water having no place to escape, falls into the next lowest part of the screw at E. At the next revolution, that portion which, during the last, was at E, will be elevated to G, for the lowest bend will receive another supply, which in the mean time will be transferred to E, and thus, by a continuance of this motion, the water is finally elevated to the discharging orifice P. This principle is readily illustrated by winding a piece of lead tube round a walking stick, and then turning the whole with one end in a dish of water, as shown in the figure.

114. "Water was sometimes raised by the ancients, by means of a rope, or bundle of ropes, as shown at Fig. 66. This mode illustrates, in a very striking manner, the force of friction between a solid and fluid, for it was by this force alone that the water was supported and elevated. The large wheel A, is supposed to stand over the well, and B, a smaller wheel, is fixed in the water. The rope is extended between the two wheels, and rises on one side in a perpendicular direction. On turning the wheel by the crank D, the water is brought up by the friction of the rope, and falling into a reservoir at the bottom of the frame which supports the wheel, is discharged at the spout D. It is evident that the motion of the wheel, and consequently that of the rope, must be very rapid, in order to raise any considerable quantity of water by this method. But when the upward velocity of the rope is eight or ten feet per second, a large quantity of water may be elevated to a considerable height by this machine."

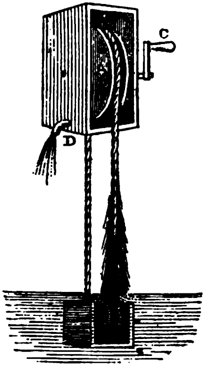

Fig. 66.

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114. Explain in what manner water is raised by the machine represented by Fig. 66.

CHAP. V.

OF PNEUMATICS.

115. "THE term Pneumatics is derived from the Greek *Pneuma*, which signifies *breath*, or *air*. It is that science which investigates the mechanical properties of air, and other elastic fluids. Under the article *Hydrostatics*, (§ 90) it was stated that fluids were of two kinds, namely, *elastic* and *inelastic*, and that air and the gases belonged to the first kind, while water and other liquids belonged to the second. The atmosphere which surrounds the earth, and in which we live, and a portion of which we take into our lungs at every breath, is called *air*, while the artificial products which possess the same mechanical properties, are called *gases*. When, therefore, the word *air* is used, it will be understood to mean the atmosphere which we breathe. Every hollow, crevice, or pore, in solid bodies, not filled with a liquid, or some other substance, appears to be filled with air: thus, a tube of any length, the bore of which is as small as it can be made, if kept open, will be filled with air; and hence, when it is said that a vessel is filled with air, it is only meant that the vessel is in its ordinary state. Indeed, this fluid finds its way into the most minute pores of all substances, and cannot be expelled and kept out of any vessel, without the assistance of the air-pump, or some other mechanical means.

116. "By the *elasticity* of air, is meant its spring, or the force with which it reacts, when compressed in a close vessel. It is chiefly in respect to its elasticity and lightness, that the mechanical properties of air differ from those of water, and other liquids. Elastic fluids differ from each other in respect to the *permanency* of the elastic property. Thus, steam is elastic only while its heat is continued, and on cooling, returns again to the form of water. Some of the gases also, on being strongly compressed, lose their elasticity,

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115. What is Pneumatics? What is air? What is gas? What is meant when it is said that a vessel is filled with air? Is there any difficulty in expelling the air from vessels?—116. What is meant by *the elasticity of air?* How does air differ from steam and some of the *gases in respect to its* elasticity? Does air lose its elastic force by being *long compressed?*

and take the form of liquids. But air differs from these, in being permanently elastic; that is, if it be compressed with ever so much force, and retained under compression for any length of time, it does not therefore lose its elasticity, or disposition to regain its former bulk, but always reacts with a force proportionate to the power by which it is compressed.

117. "Thus, if the strong tube, or barrel, Fig. 67, be smooth, and equal on the inside, and there be fitted to it the solid piston or plug A, so as to work up and down air tight, by the handle B, the air in the barrel may be compressed into a space a hundred times less than its usual bulk. Indeed, if the vessel be of sufficient strength, and the force employed sufficiently great, its bulk may be lessened a thousand times, or in any proportion, according to the force employed; and if kept in this state for years, it will regain its former bulk, the instant the pressure is removed. Thus, it is a general principle in Pneumatics, that air is compressible in proportion to the force employed.

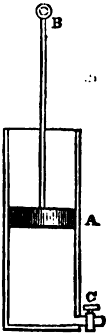

Fig. 67.

118. "On the contrary, when the usual pressure of the atmosphere is removed from a portion of air, it expands and occupies a space larger than before; and it is found by experiment, that this expansion is in a ratio as the removal of the pressure is more or less complete. Air also expands or increases in bulk when heated. If the stop-cock C, Fig. 67, be opened, the piston A may be pushed down with ease, because the air contained in the barrel will be forced out at the aperture. Suppose the piston to be pushed down to within an inch of the bottom, and then the stop-cock closed, so that no air can enter below it. Now, on drawing the piston up to the top of the barrel, the inch of air will expand, and fill the whole space, and were this space a thousand times as large, it would still be filled with the expanded air, because the piston removes the pressure of the external atmosphere from that within the barrel. It follows,

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117. In what proportion to the force employed is the bulk of air lessened?—118. In what proportion will a quantity of air increase in bulk, as the pressure is removed from it? How is this illustrated by Fig. *67? On what* circumstance, therefore, will the bulk of a given portion *of air depend?*

therefore, that the space which a given portion of air occupies, depends entirely on circumstances. If it is under pressure, its bulk will be diminished in exact proportion; and as the pressure is removed, it will expand in proportion, so as to occupy a thousand, or even a million times as much space as before.

119. "Another property which air possesses, is weight, or gravity. This property, it is obvious, must be slight, when compared with the weight of other bodies. But that air has a certain degree of gravity, in common with other ponderous substances, is proved by direct experiment. Thus, if the air be pumped out of a close vessel, and then the vessel be exactly weighed, it will be found to weigh more when the air is again admitted.

120. "*Pressure of the atmosphere.*—It is, however, the weight of the atmosphere which presses on every part of the earth's surface, and in which we live and move, as in an ocean, that here particularly claims our attention. The pressure of the atmosphere may be easily shown by the tube and piston, Fig. 68. Suppose there is an orifice to be opened or closed by the valve B, as the piston A is moved up or down in its barrel. The valve being fastened by a hinge on the upper side, on pushing the piston down it will open by the pressure of the air against it, and the air will make its escape. But when the piston is at the bottom of the barrel, on attempting to raise it again, towards the top, the valve is closed by the force of the external air acting upon it. If, therefore, the piston be drawn up in this state, it must be against the pressure of the atmosphere, the whole weight of which, to an extent equal to the diameter of the piston, must be lifted, while there will remain a vacuum or void space below it in the tube. If the piston be only three inches in diameter, it will require the full strength of a man to draw it to the top of the barrel, and when raised, if suddenly let go, it will be forced back again by the weight of the air, and will strike the bottom with great violence.

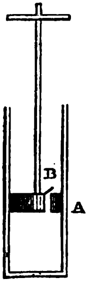

Fig. 68.

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119. How is it proved that air has weight?—120. Explain in what *manner the pressure* of the atmosphere is shown by Fig. 68. What is *the force pressing* on the piston, when drawn upwards, sometimes called?

121. "Supposing the surface of a man to be equal to 14½ square feet, and allowing the pressure on each square inch to be 15lbs., such a man would sustain a pressure on his whole surface equal to nearly 14 tons.

122. "Now, that it is the weight of the atmosphere which presses the piston down, is proved by the fact, that if its diameter be enlarged, a greater force, in exact proportion, will be required to raise it. And further, if when the piston is drawn to the top of the tube, a stop-cock, as at Fig. 68, be opened, and the air admitted under it, the piston will not be forced down in the least, because then the air will press as much on the under as on the upper side of the piston.

123. "By accurate experiments, an account of which it is not necessary here to detail, it is found that the weight of the atmosphere on every inch square of the surface of the earth is equal to fifteen pounds. If, then, a piston working air tight in a barrel, be drawn up from its bottom, the force employed, besides the friction, will be just equal to that required to lift the same piston, under ordinary circumstances, with a weight laid on it equal to fifteen pounds for every square inch of surface. The number of square inches in the surface of a piston of a foot in diameter, is 113. This being multiplied by the weight of the air on each inch, which being 15 pounds, is equal to 1695 pounds. Thus the air constantly presses on every surface, which is equal to the dimensions of a circle one foot in diameter, with a weight of 1695 pounds.

AIR-PUMP.

124. "The *air-pump* is an engine by which the air can be pumped out of a vessel, or withdrawn from it. The vessel so exhausted, is called a *receiver*, and the space thus left in the vessel, after withdrawing the air, is called a *vacuum*. The principles on which the air-pump is constructed are readily

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121. How may the pressure of the atmosphere on the surface of a man be estimated?—122. How is it proved that it is the weight of the atmosphere, instead of suction, which makes the piston rise with difficulty?—123. What is the pressure of the atmosphere on every square inch of surface on the earth? What is the number of square inches in a circle of one foot in diameter? What is the weight of the atmosphere on a surface of a foot in diameter?—124. What is the air-pump? What is the receiver of an air-pump? What is a vacuum? Explain the construction of the air-pump, with reference *to Fig. 69.*

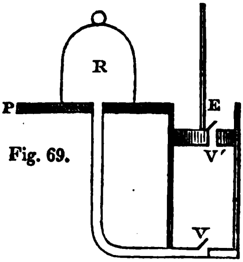

Fig. 69.

understood, and are the same in all instruments of this kind, though the form of the instrument itself is often considerably modified. The general principles of its construction will be comprehended by an explanation of Fig. 69. In this figure, let R be a glass vessel, or receiver, closed at the top, and open at the bottom, standing on a perfectly smooth plate of metal called the *plate* of the air-pump. Through the plate is an aperture, P, which communicates with the inside of the receiver, and the barrel of the pump. The piston moves air-tight through the barrel.

125. "Now, suppose the piston to be drawn up, it will then leave a free communication between the receiver R, through the orifice, to the pump-barrel in which the piston works. Then if the piston be forced down by its handle, it will compress the air in the barrel between V′ and V, and, in consequence, the valve E will be opened, and the air so condensed will be forced out. On drawing the piston up again, the valve will be closed, and the external air not being permitted to enter, a vacuum will be formed in the barrel, from V′ to V. When the piston comes again to the top of the barrel, the air contained in the glass vessel, together with that in the passage between the vessel and the pump-barrel, will rush in to fill the vacuum. Thus, there will be less air in the whole space, and consequently in the receiver, than at first, because all that was contained in the barrel is forced out at every stroke of the piston. On repeating the same process, that is, drawing up and forcing down the piston, the air at each time in the receiver will become less and less in quantity, and, in consequence, more and more rarefied. For it must be understood that, although the air is exhausted at every stroke of the pump, that which remains, by its elasticity, expands, and still occupies the whole space. The quantity forced out at each successive stroke is therefore

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125. Explain the operation of the air-pump. What is the limit to *the exhausting power of* the air-pump, as above described? Is the air-*pump capable of producing* a perfect vacuum?

diminished, until, at last, it no longer has sufficient force before the piston to open the valve, when the exhausting power of the instrument must cease entirely. Now, it will be obvious, that as the exhausting power of the air-pump depends on the expansion of the air within it, a *perfect* vacuum can never be formed by its means, for so long as exhaustion takes place, there must be air to be forced out, and when this becomes so rare as not to force open the valves, then the process must end.

126. "A good air-pump has two similar pumping barrels to that described, so that the process of exhaustion is performed in half the time that it could be performed by one barrel. The barrels, with their pistons, and the usual mode of working them, are represented by Fig. 69. The piston rods are furnished with racks, or teeth; and are worked by the toothed wheel *a*, which is turned backwards and forwards, by the lever and handle *b*. The exhaustion pipe *c*, leads to the plate on which the receiver stands, as shown in Fig. 69. The valves *r*, *n*, *u*, and *m*, all open upwards.

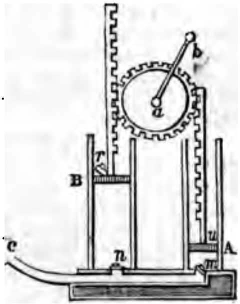

Fig. 70.

127. "To understand how these pistons act to exhaust the air from the vessel on the plate, through the pipe *c*, we will suppose that, as the two pistons now stand, the handle *b* is to be turned towards the left. This will raise the piston A, while the valve *u* will be closed by the pressure of the external air acting on it in the open barrel in which it works. There would then be a vacuum formed in this barrel, did not the valve *m* open, and let in the air coming from the receiver, through the pipe *c*. When the piston, therefore, is at the upper end of the barrel, the space between the piston and the valve *m*, will be filled with the air from the receiver.

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126. Why have common air-pumps more than one barrel and piston? How are the pistons of an air-pump worked?—127. While the piston A is ascending, which valves will be open, and which closed? When the piston A descends, what becomes of the air with which its barrel was filled? Why does not the air pass from one barrel to the other through the *valves n and m?*

Next, suppose the handle to be moved to the right, the piston A will then descend, and compress the air with which the barrel is filled, which, acting against the valve *u*, forces it open, and thus the air escapes. Thus, it is plain, that every time the piston rises, a portion of air, however rarefied, enters the barrel, and every time that it descends, this portion escapes, and mixes with the external atmosphere. The action of the other piston is exactly similar to this, only that B rises while A falls, and so the contrary. It will appear, on an inspection of the figure, that the air cannot pass from one barrel to the other, for while A is rising, and the valve *m* is open, the piston B will be descending, so that the force of the air in the barrel B, will keep the valve *n* closed. Many interesting and curious experiments, illustrating the expansibility and pressure of the atmosphere, are shown by this instrument.

128. "(1.) If a withered apple be placed under the receiver, and the air be exhausted, the apple will swell and become plump, in consequence of the expansion of the air which it contains within the skin.

"(2.) Ether, placed in the same situation, soon begins to boil without the influence of heat, because its particles, not having the pressure of the atmosphere to force them together, fly off with so much rapidity as to produce ebullition."

(3.) If a bladder, partly filled with air, and tied tightly at the neck, be placed under the receiver, and a vacuum be then produced, the air in the bladder will expand by removal of the external pressure, and perhaps burst the bladder.

(4.) Any small animal, as a mouse or bird, placed in the exhausted receiver, will immediately die, from want of breath, and from the expansion of its body.

(5.) If a long-necked flask be inverted in a vessel of water, and this apparatus be placed under the receiver, and the air rarefied by means of the pump, the air in the flask will expand and escape through the water, and, on readmitting the atmosphere, the water will rise in the flask, and occupy the space formerly occupied by the air.

(6.) If a lighted taper be placed under a receiver, and this be rapidly exhausted, the flame will be extinguished much

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128. Enumerate some experiments which may be performed by means *of the air-pump, and* which illustrate the expansibility and pressure of *the atmosphere.*

sooner than it would have been had the receiver been filled with air. It is upon the same principle that, in a vacuum, no light is produced by the collision of a flint and steel.

THE CONDENSER.

129. "The operation of the *condenser* is the reverse of that of the air-pump; it is, indeed, a much more simple machine. The air-pump, as we have just seen, will deprive a vessel of its ordinary quantity of air; the condenser, on the contrary, will double or treble the ordinary quantity of air in a close vessel, according to the force employed.

130. "This instrument, Fig. 71, consists of a pump-barrel and piston A, a stop-cock B, and the vessel C furnished with a valve opening inwards. The orifice D is to admit the air, when the piston is drawn up to the top of the barrel. To describe its action, let the piston be above D, the orifice being open, and therefore the instrument filled with air, of the same density as the external atmosphere. Then, on forcing the piston down, the air in the pump-barrel, below the orifice D, will be compressed, and will rush through the stop-cock B, into the vessel C, where it will be retained, because, on again moving the piston upward, the elasticity of the air will close the valve through which it was forced. On drawing the piston up again, another portion of air will rush in at the orifice D, and on forcing it down, this will also be driven into the vessel C; and this process may be continued so long as sufficient force is applied to move the piston, or there is sufficient strength in the vessel to retain the air. When the condensation is finished, the stop-cock B may be turned, to render the confinement of the air more secure.

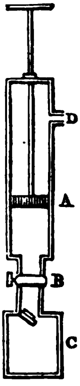

Fig. 71

131. "The magazines of *air-guns* are filled in the manner above described. The air-gun is shaped like other guns, but instead of the force of powder, that of air is employed to project the bullet. For this purpose, a strong hollow ball of

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129. How does the condenser operate?—130. Explain Fig. 71, and show in what manner the air is condensed.—131. Explain the principle of the air-gun.

copper, with a valve on the inside, is screwed to a condenser, and the air is condensed in it, thirty or forty times. This ball or magazine is then taken from the condenser, and screwed to the gun, under the lock. By means of the lock, a communication is opened between the magazine and the inside of the gun-barrel, on which the spring of the confined air against the leaden bullet is such, as to throw it with nearly the same force as gunpowder.

132. *Pressure of the atmosphere on liquids.*—We are now in a condition to make further inquiries into the phenomena of atmospheric pressure. "Suppose A, Fig 72, to be a long tube, with the piston, B, so nicely fitted to its inside as to work air-tight. If the lower end of the tube be dipped into water, and the piston drawn up, by pulling at the handle, C, the water will follow the piston so closely as to be in contact with its surface, and apparently to be drawn up by the piston, as though the whole was one solid body. If the tube be thirty-five feet long, the water will continue to follow the piston until it comes to the height of about thirty-three feet, where it will stop; and if the piston be drawn up still farther, the water will not follow it, but will remain stationary, the space from this height, between the piston and the water, being left a void space, or vacuum. The rising of the water in the above case, which only involves the principle of the common pump, is thought by some to be caused by *suction*, the piston *sucking* up the water as it is drawn upward. But, according to the common notion attached to this term, there is no reason why the water should not continue to rise above the thirty-three feet, or why the power of suction should cease at that point, rather than at any other.

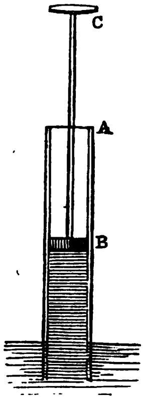

Fig. 72.

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132. Suppose the tube, Fig. 72, to stand with its lower end in the water, and the piston B to be drawn upward thirty-five feet, how far will the water follow the piston? What will remain in the tube between the piston and the water, after the piston rises higher than thirty-three feet? What is commonly supposed to make the water rise in such cases? Is there any reason why the suction should cease at thirty-three feet?

133. "Without entering into any discussion on the absurd notions concerning the power of suction, it is sufficient here to state, that it has long since been proved, that the elevation of the water in the case above described, depends entirely on the weight and pressure of the atmosphere, on that portion of the fluid which is on the outside of the tube. Hence, when the piston is drawn up, under circumstances where the air cannot act on the water around the tube, or pump-barrel, no elevation of the fluid will follow. This will be obvious by the following experiment:—Suppose Fig. 73 to represent the sections or halves of two tubes, one within the other, the outer one being made entirely close, so as to admit no air, and the space between the two being also made air-tight at the top. Suppose, also, that the inner tube being left open at the lower end, does not reach the bottom of the outer tube, and thus that an open space be left between the two tubes every where, except at their upper ends, where they are fastened together; and suppose that there is a valve in the piston, opening upwards, so as to let the air which it contains escape, but which will close on drawing the piston upwards. Now, let the piston be at A, and in this state pour water through the stop-cock, C, until the inner tube is filled up by the piston, and the space between the two tubes filled up to the same point, and then let the stop-cock be closed. If, now, the piston be drawn up to the top of the tube, the water will not follow it, as in the case first described; it will only rise a few inches, in consequence of the elasticity of the air above the water, between the tubes, and in the space above the water there will be formed a vacuum between the water and the piston, in the inner tube.

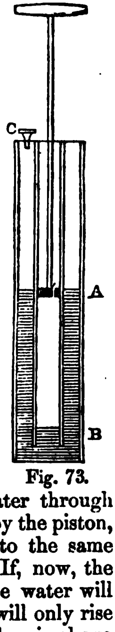

Fig. 73.

134. "The reason why the result of this experiment differs from that before described, is, that the outer tube prevents the pressure of the atmosphere from forcing the water up the

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133. What is the true cause of the elevation of the water, when the piston, Fig. 73, is drawn up? How is it shown by Fig. 73 that it is the pressure of the atmosphere which causes the water to rise in the pump-barrel?—134. Suppose the ice prevents the atmosphere from pressing on the water in a vessel, can the water be pumped out?

inner tube, as the piston rises. This may be instantly proved, by opening the stop-cock, c, and permitting the air to press upon the water, when it will be found, that as the air rushes in, the water will rise and fill the vacuum up to the piston. For the same reason, if a common pump be placed in a cistern of water, and the water is frozen over on the surface, so that no air can press upon the fluid, the piston of the pump might be worked in vain, for the water would not, as usual, obey its motion.

135. "It follows, as a certain conclusion from such experiments, that when the lower end of a tube is placed in water, and the air from within is removed by drawing up the piston, it is the pressure of the atmosphere on the water around the tube which forces the fluid up to fill the space thus left by the air. It is also proved, that the weight or pressure of the atmosphere is equal to the weight of a perpendicular column of water 33 feet high, for it is found (Fig. 72) that the pressure of the atmosphere will not raise the water more than 33 feet, though a perfect vacuum be formed to any height above this point. Experiments on other fluids prove that this is the weight of the atmosphere, for if the end of a tube be dipped in any fluid, and the air be removed from the tube, above the fluid, it will rise to a greater or less height than water, in proportion as its specific gravity is less or greater than that of water.

THE BAROMETER.

136. "*Construction of the barometer.*—The *barometer* is constructed on the principle of atmospheric pressure. This term is compounded of two Greek words, *baros*, weight, and *metron*, measure, the instrument being designed to *measure the weight* of the atmosphere. Its construction is simple, and easily understood. It is merely a tube of glass nearly filled with mercury, with its lower end placed in a vessel of the same fluid, and the upper end furnished with a scale, to mea-

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135. What conclusion follows from the experiments above described? How is it proved that the pressure of the atmosphere is equal to the weight of a column of water 33 feet high? How do experiments on other fluids show that the pressure of the atmosphere is equal to the weight of a column of water 33 feet high?—136. What is the principle on which the barometer is constructed? What does the barometer measure? *Describe the* construction of the barometer, as represented by *Fig. 74.*

sure the height of the mercury. Let A, Fig. 74, be such a tube, 34 or 35 inches long, closed at one end, and open at the other. To fill the tube, set it upright, and pour the mercury in at the open end, and when it is entirely full, place the forefinger forcibly on this end, and then plunge the tube and finger under the surface of the mercury, before prepared in the vessel B. Then withdraw the finger, taking care that in doing this, the end of the tube is not raised above the mercury in the vessel. When the finger is removed, the mercury will descend four or five inches, and after several vibrations, up and down, will rest at an elevation of 29 or 30 inches above the surface of that in the vessel, as at C. Having fixed a scale to the upper part of the tube, to indicate the rise and fall of the mercury, the barometer would be finished, if intended to remain stationary. It is usual, however, to have the tube inclosed in a mahogany or brass case, to prevent its breaking, and to have the vessel closed on the top, and fastened to the tube, so that it can be transported without danger of spilling the mercury.

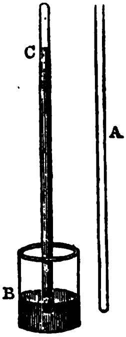

Fig. 74.

137. "It has already been shewn that it is the pressure of the atmosphere on the fluid around the tube, by which the fluid within it is forced upward, when the pump is exhausted of its air. The pressure of the air, we have also seen, is equal to a column of water 33 feet high, or of a column of mercury 29 inches high. Suppose, then, a tube 33 feet high is filled with water, the air would then be entirely excluded, and were one of its ends closed, and the other end dipped in water, the effect would be the same as though both ends were closed, for the water would not escape, unless the air were permitted to rush in and fill up its place. The upper end being closed, the air could gain no access in that direction, and the open end being under water, is equally secure. The quantity of water in which the end of the tube is placed, is not essential, since the pressure of a column of water an inch in diameter, provided it be 33 feet high, is just equal to a column of air of an inch in diameter, of the whole height of the atmosphere. Hence the water on the outside of the tube serves merely to guard against the entrance of the *external air.*

138. "The same happens to the barometer-tube, when filled with mercury. The mercury, in the first place, fills the tube perfectly, and therefore entirely excludes the air, so that when it is inverted in the cup, all the space above 29 inches is left a vacuum. The same effect precisely would be produced, were the tube exhausted of its air, and the open end placed in the cup: the mercury would run up the tube 29 inches, and then stop, all above that point being left a vacuum. The mercury, therefore, is prevented from falling out of the tube, by the pressure of the atmosphere on that which remains in the cup; for if this be removed, the air will enter, while the mercury will instantly begin to descend.

139. "In the barometer above described, the rise and fall of the mercury is indicated by a scale of inches, and tenths of inches, fixed behind the tube; but it has been found that very slight variations in the density of the atmosphere are not readily perceived by this method. It being, however, desirable that these minute changes should be rendered more obvious, a contrivance for increasing the scale, called the *wheel* barometer, was invented. The whole length of the tube of the wheel barometer, Fig. 75, from C to A, is 34 or 35 inches, and it is filled with mercury as usual. The mercury rises in the short leg to the point O, where there is a small piece of glass floating on its surface, to which there is attached a silk string, passing over the pulley P. To the axis of the pulley is fixed an index or hand, and behind this is a graduated circle, as seen in the figure. It is obvious, that a very slight variation in the height of the mercury at O, will be indicated by a considerable motion of the index, and thus changes in the weight of the atmosphere, hardly perceptible by the common barometer, will become quite apparent by this.

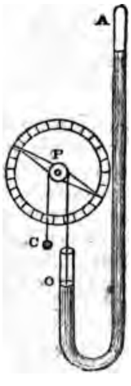

Fig. 75.

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138. What fills the space above 29 inches in the barometer tube? In *the common* barometer, how is the rise and fall of the mercury indicated? *—139. Why was the* wheel barometer invented? Explain Fig. 75, and *describe the construction* of the wheel barometer.

140. "The mercury in the barometer tube being sustained by the pressure of the atmosphere, and its medium altitude at the surface of the earth being about 29 inches, it might be expected that if the instrument were carried to a height from the earth's surface, the mercury would suffer a proportionate fall, because the pressure must be less at a distance from the earth than at its surface, and experiment proves this to be the case. When, therefore, this instrument is elevated to any considerable height, the descent of the mercury becomes perceptible. Even when it is carried to the top of a hill, or high tower, there is a sensible depression of the fluid, so that the barometer is employed to measure the heights of mountains, and the elevation to which balloons ascend from the surface of the earth. On the top of Mont Blanc, which is about 16,000 feet above the level of the sea, the medium elevation of the mercury in the tube is only 14 inches, while, on the surface of the earth, as above stated, it is 29 inches.

141. "*Uses of the barometer.*—While the barometer stands in the same place, near the level of the sea, the mercury seldom or never falls below 28 inches, or rises above 31 inches, its whole range, while stationary, being only about 3 inches. These changes in the weight of the atmosphere indicate corresponding changes in the weather, for it is found, by watching these variations in the height of the mercury, that when it falls, cloudy or falling weather ensues, and that when it rises, fine clear weather may be expected. During the time when the weather is damp and lowering, and the smoke of chimneys descends towards the ground, the mercury remains depressed, indicating that the weight of the atmosphere during such weather is less than it is when the sky is clear. This contradicts the common opinion, that the air is the heaviest when it contains the greatest quantity of fog and smoke, and that it is the uncommon weight of the atmosphere which presses these vapours towards the ground. A little

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140. What is stated to be the medium range of the barometer at the surface of the earth? Suppose the instrument to be elevated from the earth, what is the effect on the mercury? How does the barometer indicate the heights of mountains? What is the medium range of the mercury on Mont Blanc?—141. How many inches does a fixed barometer vary in height? When the mercury falls, what kind of weather is indicated? When the mercury rises, what kind of weather may be expected? When fog and smoke descend towards the ground, is it a *sign of a light* or heavy atmosphere? By what analogy is it shown that *the air is lightest* when filled with vapour?

consideration will shew that, in this case, the popular belief is erroneous, for not only the barometer, but all the experiments we have detailed on the subject of specific gravity, tend to shew that the lighter any fluid is, the deeper any substance of a given weight will sink in it. Common observation ought, therefore, to correct the error, for every body knows that a heavy body will sink in water, while a light one will swim; and by the same kind of reasoning, ought to consider, that the particles of vapour would descend through a light atmosphere, while they would be pressed up into the higher regions by a heavier air.

142. "One great use of the barometer is on board of ships, where it is employed to indicate the approach of storms, and thus to give an opportunity of preparing accordingly; and it is found that the mercury suffers a most remarkable depression before the approach of violent winds, or hurricanes. The watchful captain, particularly in southern latitudes, is always attentive to this monitor, and when he observes the mercury to sink suddenly, takes his measures without delay to meet the tempest. During a violent storm, we have seen the wheel-barometer sink a hundred degrees in a few hours. But we cannot illustrate the use of this instrument at sea, better than by giving the following extract from Dr Arnott, who was himself present at the time: 'It was,' he says, 'in a southern latitude. The sun had just set with a placid appearance, closing a beautiful afternoon, and the usual mirth of the evening watch proceeded, when the captain's orders came to prepare with all haste for a storm. The barometer had begun to fall with appalling rapidity. As yet the oldest sailors had not perceived even a threatening in the sky, and were surprised at the extent and hurry of the preparations; but the required measures were not completed, when a more awful hurricane burst upon them, than the most experienced had ever braved. Nothing could withstand it; the sails, already furled, and closely bound to the yards, were riven into tatters; even the bare yards and masts were in a great measure disabled; and at one time the whole rigging had nearly fallen by the board. Such, for a few hours, was the mingled roar of the hurricane

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142. Of what use is the barometer on board of ships? When does the mercury suffer the most remarkable depression? What remarkable instance is stated where a ship seemed to be saved by the use of the barometer?

above, of the waves around, and the incessant peals of thunder, that no human voice could be heard; and amidst the general consternation, even the trumpet sounded in vain. On that awful night, but for a little tube of mercury, which had given the warning, neither the strength of the noble ship, nor the skill and energies of her commander, could have saved one man to tell the tale.'"

WATER PUMPS.

143. There is a philosophical experiment, of which no one is ignorant. If one end of a straw be introduced into a vessel of liquid, and the other end be sucked with the mouth, the liquid will rise through the straw, and may be swallowed. Every one is familiar with the action of the common *squirt*, or hand-syringe. This instrument consists of a cylinder, or barrel, terminating in a short suction pipe, and having its interior accurately fitted with a piston. On plunging the pipe into water, and raising the piston, the liquid rushes into the barrel by atmospheric pressure, and is then projected in a continuous stream by the descent of the piston.

144. Water-pumps are machines by means of which water is elevated from various depths to the surface of the earth. There are three kinds of pump, the common suction, the lifting, and the forcing pump, so called from the manner in which they severally act.

145. *Common suction pump.*—The action of this machine depends on the principles illustrated by that of the common squirt, viz., atmospheric pressure and mechanical force. "The common pump consists of a long tube, or barrel, called the *pump-log*, which reaches from a few feet above the ground to near the bottom of the well. At A, Fig. 76, is a valve, open-

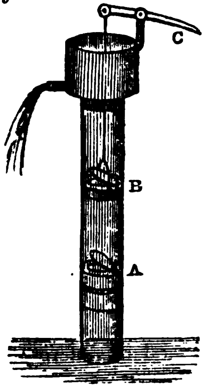

Fig. 76.

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143. What illustrations are given of the action of the common pump?—144. How many kinds of pumps are described?—145. On what does the action of the common pump depend? Which kind is the common? Describe the common pump. Explain how the common pump acts. *When the lever is depressed, what takes place in the pump-barrel? When the lever is elevated, what takes place?*

ing upwards, called the *pump-box*. When the pump is not in action, this is always shut. The piston B has an aperture through it, which is closed by a valve, also opening upwards. By the pupil who has learned what has been explained under the articles air-pump and barometer, the action of this machine will be readily understood. Suppose the piston B to be down to A, then on depressing the lever C, a vacuum would be formed between A and B, did not the water in the well rise, in consequence of the pressure of the atmosphere on that around the pump-log in the well, and take the place of the air thus removed. Then, on raising the end of the lever, the valve A closes, because the water is forced upon it, in consequence of the descent of the piston, and at the same time the valve in the piston B opens, and the water, which cannot descend, now passes above the valve B. Next, on raising the piston, by again depressing the lever, this portion of water is lifted up to B, or a little above it, while another portion rushes through the valve A to fill its place. After a few strokes of the lever, the space from the piston B to the spout, is filled with the water, where, on continuing to work the lever, it is discharged in a constant stream.

146. "Although, in common language, this is called the suction pump, still it will be observed, that the water is elevated by *suction*, or, in more philosophical terms, by atmospheric pressure, only above the valve A, after which it is raised by *lifting* up to the spout. The water, therefore, is pressed into the pump-barrel by the atmosphere, and thrown out by lifting." Although, in theory, pure water may be raised, by this machine, to a height of 35¼ feet, when the mercury stands at 31 inches in the barometer, it is not found practicable, in pumps of ordinary construction, to raise it higher than about 28 feet, the difference arising from the difficulty of making the apparatus absolutely air-tight. The several acts of respiration, suction with the mouth, drinking, smoking, &c., may all be explained by reference to the principles above-announced.

147. *Lifting pump.*—In this pump, the piston is situated

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146. How far is the water raised by atmospheric pressure, and how far by lifting? To what height may water be raised by means of the *common pump?* *Why is this* height never actually attained? *What other acts may be explained* by reference to the above principles?—147. *How does the lifting* pump differ from the common suction pump?

in the lower part of the barrel, and raises the water through the whole distance, by forcing it upward, without the agency of atmospheric pressure.

148. *Forcing pump.*—"The *forcing* pump differs from both these, in having its piston solid, or without a valve, and also in having a side pipe, through which the water is forced, instead of rising in a perpendicular direction, as in the others. The forcing pump is represented by Fig. 77, where A is a solid piston, working air-tight in its barrel. The tube, C, leads from the barrel of the air-vessel, D. Through the pipe P the water is thrown into the open air. G is a gauge, by which the pressure of the water in the air-vessel is ascertained. Through the pipe, I, the water ascends into the barrel, its upper end being furnished with a valve opening upwards.

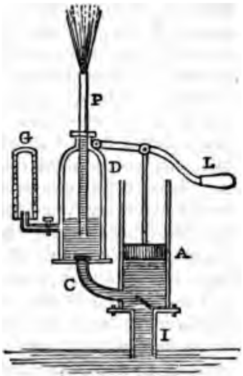

Fig. 77.

149. "To explain the action of this pump, suppose the piston to be down to the bottom of the barrel, and then to be raised upward by the lever, L, the tendency to form a vacuum in the barrel will bring the water up through the pipe, I, by the pressure of the atmosphere. Then on depressing the piston, the valve at the bottom of the barrel will be closed, and the water, not finding admittance through the pipe whence it came, will be forced through the pipe, C, and opening the valve at its upper end, will enter into the air-vessel, D, and be discharged through the pipe, P, into the open air. The water is therefore elevated to the piston barrel by the pressure of the atmosphere, and afterwards thrown out by the force of the piston. It is obvious that, by this arrangement, the height to which this fluid may be thrown, will depend on the power applied to the lever, and the strength with which the pump is made.

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148. How does the forcing pump differ from the common pump?—*149. Explain* Fig. 77, and shew in what manner the water is brought up *through* the pipe, I, and afterwards thrown out at the pipe, P.

150. "The air-vessel, D, contains air in its upper part only, the lower part, as we have already seen, being filled with water. The pipe, P, called the discharging pipe, passes down into the water, so that the air cannot escape. The air is therefore compresssed, as the water is forced into the lower part of the vessel, and reacting upon the fluid by its elasticity, throws it out of the pipe in a continued stream. The constant stream which is emitted from the direction-pipe of the fire-engine, is entirely owing to the compression and elasticity of the air in its air-vessel. In pumps without such a vessel, as the water is forced upwards only while the piston is acting upon it, there must be an interruption of the stream while the piston is ascending, as in the common pump. The air-vessel is a remedy for this defect, and is found also to render the labour of drawing the water more easy, because the force with which the air in the vessel acts on the water, is always in addition to that given by the force of the piston."

151. In each of the pumps above-described, the total effort required to work the machine, independently of friction, is equal to the weight of a column of water, the base of which is equal to the area of a section of the working barrel, and the altitude equal to the distance between the surface of the water in the reservoir and the point to which it is raised. In the suction pump, the whole of the effort is expended in raising the piston; in the forcing pump, one part is expended in raising, and the other in depressing the piston, and it is advantageous to arrange the machinery, so that these two parts shall be nearly equal. In small pumps employed for domestic purposes, the strength of man is usually exerted as the moving power; but in raising water from great depths, as from the bottom of mines, the steam-engine is usually employed.

152. *Chain pump.*—This kind of pump is used on board of ships, and consists of an endless chain moving over a wheel on the deck, which is turned round by winches, and over a roller in the pump-well, having saucers or flat circular pistons at certain intervals. Near the pump-well, on the side on

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150. Why does not the air escape from the air-vessel in this pump? What effect does the air-vessel have on the stream discharged? Why does the air-vessel render the labour of raising the water more easy?—*151. In the several pumps* now described, to what is the effort required *to work them proportioned*?—152. What is the construction of the *chain pump?* What is its effect per minute?

which the chain on turning the winches ascends, are a few feet of pipe; through this the saucers raise the column of water, which, being lifted over the upper orifice of the pipe, falls into the cistern, and thence into the waste pipe, called the *pump-dale*, which carries it overboard. The descending portion of chain falls through another case, called the *back-case.* Chain pumps, in large ships, throw out a ton of water per minute.

FIRE ENGINE.

153. "The *fire engine* is a modification of the forcing pump. It consists of two such pumps, the pistons of which are moved by a lever with equal arms, the common fulcrum being at C, Fig. 78. While the piston A is descending, the other piston B is ascending. The water is pressed by the pressure of the atmosphere through the common pipe P, and then dividing, ascends into the working barrels of each piston, where the valves, on both sides, prevent its return. By the alternate depression of the pistons, it is then forced into the air-box D, and then, by the direction pipe E, is thrown where it is wanted. This machine acts precisely like the forcing pump, only that its power is doubled, by having two pistons instead of one.

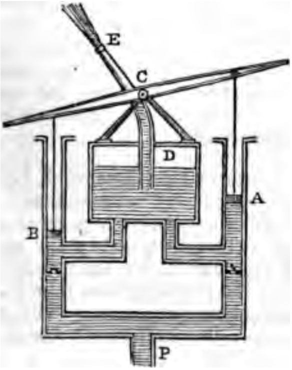

Fig. 78.

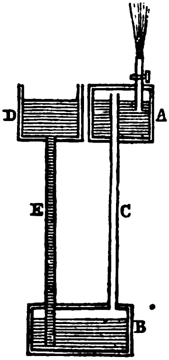

Fig. 79.

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153. Explain Fig. 78, and describe the action of the fire engine. *What causes the continued stream from the direction pipe of this engine?*

154. "There is a beautiful fountain called the *fountain of Hiero*, which acts by the elasticity of the air, and on the same principle as that already described. Its construction will be understood by Fig. 79, but its form may be varied according to the dictates of fancy or taste. The boxes A and B, together with the tubes, are made air-tight, and strong in proportion to the height it is desired the fountain should play. To prepare the fountain for action, fill the box A, through the spouting tube, nearly full of water. The tube C, reaching nearly to the top of the box, will prevent the water from passing downwards, while the spouting pipe will prevent the air from escaping upwards, after the vessel is about half filled with water. Next, shut the stop-cock of the spouting pipe, and pour water into the open vessel D. This will descend into the vessel B through the tube E, which nearly reaches its bottom, so that, after a few inches of water are poured in, no air can escape, except by the tube C, up into the vessel A. The air will then be compressed by the weight of the column of water in the tube E, and therefore the force of the water from the jet pipe will be in proportion to the height of this tube. If this tube is 20 or 30 feet high, on turning the stop-cock, a jet of water will issue from the pipe."

CHAP. VI.

OF ACOUSTICS.

155. *Undulations.*—The constituent particles of all bodies are usually held, by the operation of certain internal and external forces, in a state of equilibrium; and, where these particles have been to a certain extent disturbed by any cause, they return to the state of equilibrium, by alternately approaching the position of rest and receding from it, until, by a gradually decreasing recession, they attain the condition of repose. These movements are called ***undulations***, ***vibrations***, or *oscillations*.

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154. How is the fountain of Hiero constructed? On what will the *height of the jet from* Hiero's fountain depend?—155. What is meant by *undulations, vibrations, or* oscillations?

156. Vibration may take place in all *solid* bodies which possess a requisite degree of elasticity. The elastic force necessary for vibration may either be an innate property of the mass, as in rods and plates of metal, and glass; or it may be acquired by means of tension, as in cords and membranes. Bodies of a *linear* form are capable of exhibiting three kinds of vibration, the transverse, the longitudinal, and the rotatory. 1. If a piece of whip cord be strained tight and firmly held at each end, and be then pulled in the middle from its position of rest, and suddenly let go, it undergoes a series of *transverse* vibrations. 2. If the cord be held at one end, and a weight attached to the other end be raised, and then let go, a series of *longitudinal* vibrations is produced. 3. Lastly, if the cord be twisted by means of the weight, and the weight be suddenly allowed to fall, the cord exhibits a series of *rotatory* vibrations. To the subject of vibration of solid bodies we shall presently have occasion to return.

157. Undulation is produced in non-elastic, or *liquid* bodies, as water, either by dropping a solid body into the liquid, or by withdrawing an immersed solid from the liquid. Around the point of impression a circular elevation is formed on the surface of the water, and immediately adjoining it is a corresponding depression; these constitute a *circular undulation*. The wave, thus produced, traverses the surface of the water, and a series of concentric circles is formed, each of which becomes progressively larger, as it travels further from the point of impression. These alternate elevations and depressions, gradually decrease in height and depth, until at length the equilibrium is restored.

158. Undulation occurs in elastic, or *fluid* bodies, as atmospheric air, by any cause which disturbs the equilibrium. If an impulse of any kind be imparted to the air at any point, it will be communicated to the surrounding contiguous particles, in all directions with equal velocity. A *sphere of air* is thus formed around the point of impulse, the expansion of which is gradually arrested by the reaction of the condensed air, until, at last, the sphere contracts, and the air recovers its former equilibrium.

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156. **What solid bodies possess this property? Explain the three kinds of vibration which occur in solid bodies of lineal form.—157. Explain the undulations of liquid bodies.—158. What is the effect of an *impulse* communicated to a fluid body?**

159. By the term ACOUSTICS is denoted that branch of natural philosophy which treats of the origin, propagation, and effects of sound. When a sonorous or sounding body is struck, it is thrown into a tremulous or vibrating motion. This motion is communicated to the surrounding air, and is conveyed by this medium to the drum of the ear, which also undergoes a vibratory motion, and this last motion, by throwing the auditory nerves into action, produces the sensation of hearing. The phenomena of sound have in many particulars a strong analogy to those of light. Hooke and Euler supposed both to consist in a mere vibration, or impulse of ether, or air. Newton contended for a peculiar luminous fluid, or matter of light, distinct from ether; and Epicurus for a peculiar sonorous fluid, or matter of sound, distinct from air; an opinion which Lamarck appears to have revived in our own times.

160. "If any sounding body of considerable size is suspended in the air, and struck, this tremulous motion is distinctly visible to the eye, and while the eye perceives its motion, the ear perceives the sound. That sound is conveyed to the ear by the motion which the sounding body communicates to the air, is proved by an interesting experiment with the air-pump. Among philosophical instruments, there is a small bell, the hammer of which is moved by a spring connected with clock-work, and which is made expressly for this experiment. If this instrument be wound up, and placed under the receiver of an air-pump, the sound of the bell may at first be heard to a considerable distance, but as the air is exhausted, it becomes less and less audible, until no longer to be heard, the strokes of the hammer, though seen by the eye, producing no effect upon the ear. Upon allowing the air to return gradually, a faint sound is at first heard, which becomes louder and louder, until as much air is admitted as was withdrawn.

161. "On the contrary, when the air is more dense than ordinary, or when a greater quantity is contained in a vessel,

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159. What is meant by acoustics? When a sonorous body is struck, in what manner do we gain from it the sensation of sound? Explain the analogy supposed to exist between the phenomena of sound and those of sight.—160. How is it proved that sound is conveyed to the ear *by the medium of the* air?—161. When the air is more dense than usual, *how does it affect sound?* What is said of the effects of sound on the *tops of high mountains?*

than in the same space in the open air, the effect of sound on the ear is increased. This is illustrated by the use of the diving-bell. When this machine is sunk to any considerable depth, the water above, by its pressure, condenses the air under it with great force. In this situation, a whisper is as loud as a common voice in the open air, and an ordinary voice becomes painful to the ear. Again, on the tops of high mountains, where the pressure or density of the air is much less than on the surface of the earth, the report of a pistol is heard only a few rods, and the human voice is so weak as to be inaudible at ordinary distances. Thus, the atmosphere which surrounds us is the medium by which sounds are conveyed to our ears, and to its vibrations we are indebted for the sense of hearing, as well as for the pleasure derived from the sounds of music.

162. "The atmosphere, though the most common, is not, however, the only, or the best conductor of sound. Solid bodies conduct sound better than elastic fluids. Hence, if a person apply his ear to a long stick of timber, the scratch of a pin may be heard from the other end, which could not be perceived through the air. The earth conducts loud rumbling sounds made below its surface to great distances. Thus, it is said, that in countries where volcanoes exist, the rumbling noise which generally precedes an eruption, is heard first by the beasts of the field, because their ears are commonly near the ground, and that by their agitation and alarm, they give warning of its approach to the inhabitants. The American Indians discover the approach of horses or men, by laying their ears on the ground, when they are at such distances as not to be heard in any other manner."

163. The rate of velocity at which sound is propagated through the air, has been variously estimated. When a gun is fired at a considerable distance, the flash is seen a certain time before the report is heard; and the same phenomenon is observed with respect to the stroke of a hammer, the fall of a stone, or any visible action which produces a sound. The method generally adopted for ascertaining the velocity

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162. Which are the best conductors of sound, solid or elastic substances? What is said of the earth as a conductor of sound? How is it said that the Indians discover the approach of horses or men?—163. How is the rate of velocity of sound estimated? Does sound travel at a *uniform* rate? How may the velocity with which the report of a gun travels be estimated?

of sound, is, to measure, by means of a stop watch or pendulum, the time which elapses between the appearance of the flash, and the hearing of the report of a gun fired at a certain measured distance from the observer; for light travels so fast through a distance of 1000 or 2000 miles, that we cannot possibly appreciate the time; we may, therefore, conclude that the explosion of a gun takes place at the very moment in which the flash is perceived. Now, it has been invariably noticed, that sound travels at a uniform rate: thus, it will travel twice as far in two seconds, as it will in one second; that it will travel three times as far in three seconds, as it will in one, and so on. Therefore, in this manner of estimating the velocity of sound, if the distance, in feet, between the gun and the observer, be divided by the number of seconds which elapse between the perceptions of the flash and of the report, the quotient will show the rate of travelling, or how many feet per second are traversed by the sound.

164. The experiments and calculations of Derham, Flamstead, and Halley, lead to the general conclusion that sound travels uniformly through the atmosphere at the rate of 1142 feet per second, or one mile in little less than five seconds; at least, this result cannot differ from the truth by more than fifteen or twenty feet. The difficulty, however, of measuring time to a fraction of a second, is too great to admit of absolute accuracy. 1. Derham observed, that the report of a cannon fired at a distance of thirteen miles, did not strike on his ear as a single sound, but was repeated five or six times close to each other. "The first two cracks," he says, "were louder than the third, but the last cracks were louder than any of the rest. And, besides, in some of my stations, besides the multiplied sound, I plainly heard a faint echo, which was reflected by my church, and the houses adjacent." 2. This repetition of the sound was probably caused by reflection of a single sound from hills, houses, or other objects, not very distant from the cannon. But it appears, from general observation, and where no echo can be suspected, that the sound of a cannon, at a distance of ten or twenty miles, dif-

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164. At what velocity does sound travel through the atmosphere? Describe the effect produced by the report of a cannon at the distance of *thirteen* miles. How may this effect be explained? What difference is *observed in the quality* of sound proceeding from a long, and from a *short distance? What circumstances should be taken into consideration, in estimating the velocity* of sound through the air?

fers from a sound proceeding from an object which is near. In the latter case, the crack is loud and instantaneous, and we are unable to appreciate its height; whereas, in the former case, it is a grave sound, which may be compared with a determinate musical sound, and, instead of being instantaneous, it begins softly, swells to its extreme loudness, and then dies away. Nearly the same thing may be observed with respect to a clap of thunder. Other sounds are likewise altered in quality by the distance through which they are propagated. 3. In estimating the velocity of sound, the state of the atmosphere, with regard to wind, must be taken into consideration. But the velocity of the air in the strongest wind is, perhaps, not equal to the twentieth part of the velocity of sound. 4. A slight alteration in the velocity of sound is occasioned by difference of temperature; the propagation of sound is rather quicker in summer than in winter. 5. Different altitudes of the barometer, as also different quantities of moisture in the atmosphere, occasion slight variations in the velocity of sound, but these variations cannot be determined with reference to these causes respectively.

165. Upon the whole it appears, that whatever increases the elasticity of the air, accelerates the motion, as also the intensity, of sound through this medium, and *vice versâ*. Or, in fluids of a determinate elasticity, whatever increases the density, diminishes the velocity of sound through them. Probably the velocities of sound through such fluids, are as the squares of the densities. Experience seems to prove, that at different seasons of the year, the influence of the winds being excluded, the velocity of sound may be faster or slower, not exceeding thirty feet, than at the above-mentioned mean rate of 1142 feet per second.

166. The knowledge of the velocity of sound through the air may be applied to the measurement of distances. The distance of a thunder cloud, for instance, may be estimated by measuring the time which elapses between the appearance of the flash of lightning and the report of the explosion or thunder; for if, by looking on a watch with a second's hand, we find the interval to be one second, we may conclude that the explosion took place at the distance of 1142 feet

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165. *To what extent does the velocity of sound through the air differ in different seasons throughout the year?*—166. *How may the distance of a thunder-cloud be determined by the velocity of sound?*

from us; if the interval be two, three, or any other number of seconds, we may conclude that the distance is the product of 1142, multiplied by the number of seconds. In the same manner, by observing the flash and the report of a gun, or the motion of the hand which moves a hammer, and the perception of the sound, we may determine, approximately, the distance of a ship, of an island, of a workman, &c.

167. "Solid substances convey sounds with greater velocity than air, as is proved by the following experiment, lately made at Paris, by M. Biot. At the extremity of a cylindrical tube, upwards of 3000 feet long, a ring of metal was placed, of the same diameter as the aperture of the tube; and in the centre of this ring, in the mouth of the tube, was suspended a clock-bell and hammer. The hammer was made to strike the ring and the bell at the same instant, so that the sound of the ring would be transmitted to the remote end of the tube, through the conducting power of the tube itself, while the sound of the bell would be transmitted through the medium of the air inclosed in the tube. The ear being then placed at the remote end of the tube, the sound of the ring, transmitted by the metal of the tube, was first heard distinctly, and after a short interval had elapsed, the sound of the bell, transmitted by the air in the tube, was heard. The result of several experiments was, that the metal conducted the sound at the rate of about 11,865 feet per second, which is about ten and a half times the velocity with which it is conducted by the air."

168. The following are the results of Chladni's experiments, as stated by himself:—"Articulated tones are also conducted exceedingly well through hard bodies, as I found by experiments which I made with some of my friends. Two persons who stopped their ears could converse with each other, when they held a long stick, or a series of sticks, between their teeth, or rested their teeth against them. It is all the same whether the person who speaks rests the stick against his throat or his breast, or whether one rests the stick, which he holds in his teeth, against some vessel into which the other speaks. The effect will be greater, the more the

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167. Which convey sounds with the greatest velocity, solid substances, or air? Describe the experiment proving that sound is conducted by a metal with greater velocity than by the air.—168. *In what lines does sound move?*

vessel is capable of a tremulous movement. It appeared to be strongest with glass and porcelain vessels; with copper kettles, wooden boxes, and earthen pots, it was weaker. Sticks of glass, and next fir-wood, conducted the sound best. The sound could also be heard when a thread was held between the teeth by both, so as to be somewhat stretched. Through each substance, the sound was modified in a manner a little different. By resting a stick, or other body, against the temples, the forehead, and the external cartilaginous part of the ear, sound is conveyed to the interior organs of hearing; as will readily appear, if you will hold your watch to those parts of another person who has stopped up his ears. From this it appears, as well as from the experiments relative to the hearing under water, that hearing is nothing else than, by means of the organs of hearing, to be sensible of the tremulous movement of an elastic body, whether this tremulous movement be conveyed through the air, or any other fluid or hard body, to the auricular nerves. It is also essentially the same, whether, as is usually the case, the sound be conveyed through the internal part of the ear, or whether it be communicated through any other part of the body. It certainly would be worth the trouble to make experiments, to try whether it might not be possible that deaf and dumb people, when the deficiency lies only in the external organs of the ear, the auricular nerve being perfect, could not, by the above method of conducting sound, be made to hear distinctly words articulated, as well as other sounds."

169. *Echo.*—"Sound moves forward in straight lines, and in this respect follows the same laws as moving bodies, and light. It also follows the same laws in being reflected, or thrown back, when it strikes a solid, or reflecting surface. If the surface be smooth, and of considerable dimensions, the sound will be reflected, and an *echo* will be heard; but if the surface be very irregular, soft, or small, no such effect will be produced. In order to hear the echo, the ear must be placed in a certain direction, in respect to

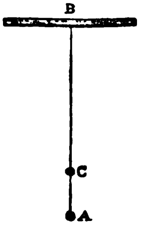

Fig. 80.

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169. From what kind of surface is sound reflected, so as to produce *an echo?* Explain Fig. 80.

the point where the sound is produced, and the reflecting surface. If a sound be produced at A, Fig. 80, and strike the plain surface B, it will be reflected back in the same line, and the echo will be heard at C or A: that is, the angle under which it approaches the reflecting surface, and that under which it leaves it, will be equal.

170. "Whether the sound strike the reflecting surface at right angles or obliquely, the angle of approach, and the angle of reflection, will always be the same, and equal. This is illustrated by Fig. 81, where, suppose a pistol to be fired at A, while the reflecting surface is at C, then the echo will be heard at B, the angle 2 and 1 being equal to each other.

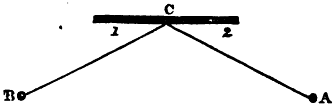

Fig. 81.

171. "If a sound be emitted between two reflecting surfaces, parallel to each other, it will reverberate, or be answered backwards and forwards several times. Thus, if the sound be made at A, Fig. 82, it will not only rebound back again to A, but will also be reflected from the points C and D; and were such reflecting surfaces placed at every point around a circle from A, the sound would be thrown back from them all, at the same instant, and would meet again at the point A. It is a fact well ascertained in optics, that light observes exactly the same law in respect to its reflection from plane surfaces, and that the angle at which it strikes, is called the *angle of incidence*, and that under which it leaves the reflecting surface is called the *angle of reflection*. The same terms are employed in respect to sound.

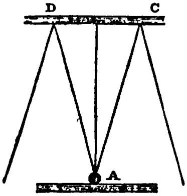

Fig. 82.

172. "In a circle, as mentioned above, sound is reflected

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170. Explain Fig. 81, and show in what direction sound approaches and leaves a reflecting surface.—171. What is the angle under which sound strikes a reflecting surface called? What is the angle under which it leaves a reflecting surface called? Is there any difference in *the quantity of these two angles?*—172. Suppose a pistol to be fired in the *centre of a circular room*, where would be the echo? Explain Fig. 82, *and give the reason.*

from every plane surface placed around it, and hence, if the sound is emitted from the centre of a circle, this centre will be the point at which the echo will be most distinct. Suppose the ear to be placed at the point A, Fig. 83, in the centre of a circle; and let a sound be produced at the same point, then it will move along the line A E, and be reflected from the plane surface, back on the same line to A; and this will take place from all the plane surfaces placed around the circumference of a circle; and, as all these surfaces are at the same distance from the centre, so the reflected sound will arrive at the point A, at the same instant; and the echo will be loud, in proportion to the number and perfection of these reflecting surfaces. It is apparent that the auditor, in this case, must be placed in the centre from which the sound proceeds, to receive the greatest effect.

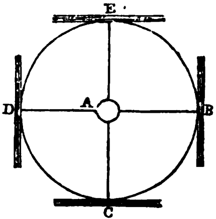

Fig. 83.

173. "But if the shape of the room be oval, or elliptical, the sound may be made in one part, and the echo will be heard in another part, because the ellipse has two points, called foci, at one of which, the sound being produced, it will be concentrated in the other. Suppose a sound to be produced at A, Fig. 84, it will be reflected from the sides of the room, the angles of incidence being equal to those of reflection, and will be concentrated at B. Hence a hearer standing at B, will be affected by the united rays of sound from different parts of the room, so that a whisper at A, will become audible at B, when it would not be heard in any other part of the room. Were the sides of the room lined with a polished metal, the rays of light or heat would be concentrated in the same manner. The reason of this will be understood, when we consider, that an ear, placed at

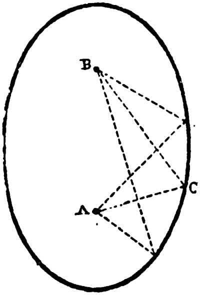

Fig. 84.

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173. Suppose a sound to be produced in one of the foci of an ellipse, *where then might it be distinctly heard?* Explain Fig. 84, and give the *reason.*

C, will receive only one ray of the sound proceeding from A, while if placed at B, it will receive from all parts of the room. Such a room, whether constructed by design or accident, would be a *whispering gallery.*"

174. Several reflecting surfaces may be so situated, in respect to distance and direction, that a sound, proceeding from a certain point, will be reflected first by one surface, then by another at a little distance, afterwards by a third, and so on; or it will be reflected from the first surface to the second, from the second to the third, and so on; hence a sound may be repeated several times.

175. According to the distance at which the speaker stands, a reflecting object will return an echo of several, or of fewer syllables; for, in order to avoid confusion, all the syllables must be uttered before the echo of the first syllable reaches the ear. In a moderate way of speaking, about 3½ syllables are pronounced in one second, or seven syllables in two seconds. Therefore, when an echo repeats seven syllables, the reflecting object is 1142 feet distant; for sound travels at the rate of 1142 feet per second, and the distance from the speaker to the reflecting object, and again from the latter to the former, is twice 1142 feet. When the echo returns fourteen syllables, the reflecting object must be 2284 feet distant, and so on. It is stated that a famous echo in Woodstock park repeats seventeen syllables in the day, and twenty at night. On the north side of Shepley church, in Sussex, it is said that an echo repeats distinctly, under favourable circumstances, twenty-one syllables.

176. "On a smooth surface, the rays, or pulses of sound, will pass with less impediment than on a rough one. For this reason, persons can talk to each other on the opposite sides of a river, when they could not be understood to the same distance over the land. The report of a cannon, at sea, when the water is smooth, may be heard at a great distance, but if the sea is rough, even without wind, the sound will be broken, and will reach only half as far." In favourable circumstances, the striking of the clock on the bell of St.

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174. By what means may a repetition of reflected sounds be heard? —175. How is reflected sound affected by distance? What is the rate of distance at which a certain number of syllables may be echoed?— *176. Why is it that persons can converse on the opposite sides of a river, when they could* not hear each other at the same distance over the *land? At what distance* has the human voice been heard?

Paul's Church, in London, has been heard at Windsor. It has been said that, with a particular concurrence of favourable circumstances, the human voice has been heard at the distance of more than ten miles, viz., from Old Gibraltar to New Gibraltar.* The discharge of an ordinary musket can hardly ever be heard further than seven or eight miles; but the discharge of several such muskets, at the same time, may be heard from a greater distance. The quick repetition of the same sound may also be heard somewhat further than the same singly. In the Dutch war of the year 1672, it has been said, that the reports of the cannons were heard at the distance of 200 miles, and upwards.

MUSICAL SOUNDS.

177. "The *strings* of *musical instruments* are elastic cords, which being fixed at each end, produce sounds by their vibration. The string of a *violin* or *pianoforte*, when pulled to one side by its middle, and let go, vibrates backwards and forwards like a pendulum, and striking rapidly against the air, produces tones, which are grave or acute according to its tension, size, or length. The manner in which such a string vibrates is shown by Fig. 85.

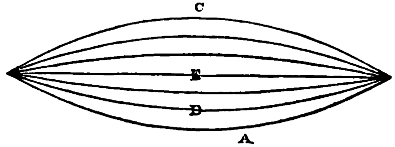

Fig. 85.

If pulled from E to A, it will not stop again at E, but in passing from A to E, it will gain a momentum, which will carry it to C, and in returning, its momentum will again carry it to D, and so on, backwards and forwards, like a pendulum, until its tension, and the resistance of the air, finally bring it to rest.

178. "The *grave* or *sharp* tones of the same string depend

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177. How is tone produced by the string of a violin or piano forte?—178. On what does the difference between a *grave* and a *sharp* tone depend? Why are the bass strings of instruments covered with metallic wire?

* *Derham's* Physico-Theology, B. iv. chap. 3. See also the Phil. Trans. No. 300, *for more facts of this nature.*

on its different degrees of tension; hence, if a string be struck, and while vibrating, its tension be increased, its tone will be changed from a lower to a higher pitch. Strings of the same length are made to vibrate slow or quick, and consequently to produce a variety of sounds, by making some larger than others, and giving them different degrees of tension. The *violin* and *bass viol* are familiar examples of this. The low, or bass strings, are covered with metallic wire, in order to make their magnitude and weight prevent their vibrations from being too rapid, and thus they are made to give deep or grave tones. The other strings are diminished in thickness, and increased in tension, so as to make them produce a greater number of vibrations in a given time, and thus their tones become sharp or acute in proportion.

179. "Under certain circumstances, a long string will divide itself into halves, thirds, or quarters, without depressing any part of it, and thus give several harmonious tones at the same time. The fairy tones of the *Æolian harp* are produced in this manner. This instrument consists of a simple box of wood, with four or five strings, two or three feet long, fastened at each end. These are tuned in unison, so that when made to vibrate with force, they produce the same tones. But when suspended in a gentle breeze, each string, according to the manner of force in which it receives the blast, either sounds as a whole, or is divided into several parts, as above described. 'The result of which,' says Dr Arnott, 'is the production of the most pleasing combination and succession of sounds that the ear ever listened to, or fancy perhaps conceived. After a pause, this fairy harp is often heard beginning with a low and solemn note, like the bass of distant music in the sky; the sound then swells as if approaching, and other tones break forth, mingling with the first and with each other.'

180. "The manner in which a string vibrates in parts will be understood by Fig. 86. Suppose the whole length of the

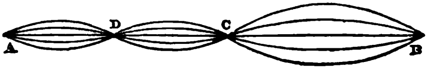

Fig. 86.

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179. Why does the Æolian harp yield a variety of tones, since all the *strings are tuned in unison?*—180. Explain Fig. 86, showing the manner *in which strings vibrate in parts.*

string to be from A to B, and that it is fixed at these two points. The portion from B to C vibrates as though it was fixed at C, and its tone differs from those of the other parts of the string. The same happens from C to D, and from D to A. While a string is thus vibrating, if a small piece of paper be laid on the part C or D, it will remain, but if placed on any other part of the string, it will be shaken off."

181. When the vibrations of a string succeed each other with such regularity as to produce the impression of a single sound, this is called a *musical sound.* Musical sounds differ from each other, partly in regard to quantity, partly in quality. 1. The *quantity* of a musical sound depends on the extent and velocity of the vibrations, and therefore corresponds to the *strength* or *intensity* of the sound. Thus, the further a string is drawn from its position of rest, the louder will be its sound; the more violently a bell is shaken, the louder will it ring. Musical sounds are termed *notes*, and are distinguished as *high* and *low*, with reference to the number of vibrations: if two notes be sounded at the same time, that which is produced by the greater number of vibrations, is called the higher note; thus, if a cord, while vibrating through its entire length, be suddenly shortened, its vibrations will be more rapid, and the note will be raised. 2. The *quality* of a sound relates to the different bodies by which it is produced. If two notes of similar intensity be produced, the one by the human voice, the other by a tense string or by a bird, the quality of each is readily appreciated by the ear, though no account can be given of the different emotions occasioned by them.

182. The capacity of the human ear for appreciating the vibrations of a sonorous body is restricted within certain limits. It has been proved by experiment, that the lowest note we are capable of perceiving is that produced by a body performing 32 half-vibrations, or 16 impulses, in one second of time; and the highest, that which is performed by 16,000 in the same period of time. It is stated, however, that a finely attuned ear is capable of appreciating, as a distinct sound, a kind of hissing noise occasioned by the performance of 48,000 half vibrations, or 24,000 impulses, in a second of time.

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181. What constitutes a musical sound? What is meant by the *quantity of a sound?* What, by its quality?—182. Within what limits *is the human* ear capable of appreciating musical sounds?

183. *Scale of musical notes* —The principal notes, or musical sounds, are seven in number. In this country they are designated by the first seven letters of the alphabet in a peculiar arrangement, as C, D, E, F, G, A, B. On the continent, the seven syllables, Do, Re, Mi, Fa, Sol, La, Si, are usually preferred. These *notes* constitute what is called the *gamut*, or *diatonic scale.* On investigating the cause why this combination of seven sounds strikes the ear with agreeable sensations, it is found to depend on the simplicity of the relation between the notes, with reference to the number of their vibrations. Such a relation is called an *interval.* The simplest interval of musical sounds is that in which the higher note performs twice as many vibrations as the *fundamental note* from which it is derived. Such an interval is called an *octave*, and its relation is therefore as 1 is to 2, 2 to 4, 4 to 8, &c. A collection of eight consecutive notes constitutes an octave; the first of these, supposing it to be C, performs 258 vibrations in a second of time, while the eighth, also called C, performs 516 vibrations in the same space of time; the latter note is commonly said to be pitched *an octave higher* than the former. By way of illustrating this fact, let us suppose that a cord of forty-five inches in length, stretched between two pegs on a board, as in the piano-forte, produces the note C of 258 vibrations in a second. Let the cord be now pressed down by the finger exactly in the centre, and either half of it be struck, or made to vibrate; the consequence will be that a much shriller, or higher, note will be produced. This note is also called C, but it is the first note of a new series, and, for its production, 516 vibrations were performed in a second of time. This is upper C, or the octave of the fundamental C, which was produced by half the number of vibrations. Each of the seven notes is capable of being raised an octave higher by a similar experiment.

184. Between the fundamental interval of the *octave*, there

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183. What are the principal notes of music termed? On what does the agreeable sensation produced by them in succession depend? What is an octave? What relation exists between the fundamental note and its octave? How may this be illustrated?—184. How many intervals occur in unison between the fundamental interval of the octave? Assuming the cord of forty-five inches to yield the fundamental note C, and *calling this cord 1*, what length of cord will be required to form the other *notes of the diatonic scale?* What is the proportion of the number of *vibrations to the lengths of* cord, respectively?

exist many other intervals, of which, however, there are but six, which, when heard in succession, fall in unison upon the ear. In investigating the characters of these notes, we cannot help being struck with the fact, that the science of music, apparently so independent of abstract mathematics, is nevertheless based on certain fixed relations of numbers; and that the harmony of notes is intimately connected with the coincidence of simple numerical ratios. Assuming the cord of forty-five inches, above mentioned, to yield the note C, and calling it 1, its octave will require one-half of the length of the cord; and the intermediate notes will require *lengths of cord* in the following proportions:—for D, eight-ninths; for E, four-fifths; for F, three-fourths; for G, two-thirds; for A, three-fifths; and for B, eight-fifteenths. All these proportions are exactly reversed, with regard to the *number of vibrations*, which are, respectively, nine-eighths, five-fourths, four-thirds, three-seconds, five-thirds, and fifteen-eighths. All this will be rendered clearer by the following table, in which the names of the notes, the comparative lengths of the cord, and number of vibrations producing them, together with the absolute (approximate) number of vibrations performed in a second of time, in order to produce a particular note, are placed together:—

Names of Notes.		Comparative		Absolute (approximate) number of vibrations in a second.
Foreign.	English.	Length of Cord.	Number of Vibrations.	
Do	C	1	1	258
Re	D	$\frac{8}{9}$	$\frac{9}{8}$	290
Mi	E	$\frac{4}{5}$	$\frac{5}{4}$	322
Fa	F	$\frac{3}{4}$	$\frac{4}{3}$	344
Sol	G	$\frac{2}{3}$	$\frac{3}{2}$	387
La	A	$\frac{3}{5}$	$\frac{5}{3}$	430
Si	B	$\frac{8}{15}$	$\frac{15}{8}$	483
Do	C	$\frac{1}{2}$	2	516

185. Of the seven notes above described, there are three which are more apportioned to each other than the rest, and which consequently form the most agreeable combination to the ear. These are C, E, and G; and this chord of three notes

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185. What is a triad, and of what notes is it composed? On what ***does the pleasurable*** **emotions produced by the triad depend?**

is called a *triad.* In this case, also, it appears that the pleasurable emotion occasioned by the combination depends on the simplicity of the ratios of vibration, for in the time that C, or the fundamental note, performs 4 vibrations, its *third* E performs 5, and its fifth G, 6. This combination of the fundamental note C with the major third E and the fifth G is called the *perfect major chord.*

186. There are some curious facts connected with the harmonious notes. "The *cries* of a city—that is, the scarcely articulate, but often very musical, sounds uttered by persons selling things in the streets,—generally rise on *thirds* or *fifths,* sometimes on *octaves;* and this, although few of these poor people have been taught music. The cry of oysters by women in Edinburgh is always on an octave. Teachers of elocution are also aware that human beings in general make such transitions of voice naturally, under the influence of certain feelings. For example, a person indifferently surprised at hearing a friend say, 'I was the person who did so and so,' will say, 'Was it you?' rising only a *third* at the last word. If greatly surprised, the rise will be a *fifth.* There may be even so great a degree of astonishment, that the word 'you' will begin on one note and terminate on its octave. The answers, 'Yes, it was I,' will show corresponding declensions or falls of voice. We thus see how truly music is a species of natural language. Unquestionably, every shade of human feeling can be represented by succession of its sounds, apart altogether from words."—*Chambers's Information for the People.*

187. The limits of this work will not admit of minute details of this interesting branch of acoustics. A few remarks must, however, be added on the *chromatic scale.* By referring to the diatonic scale, above described, it will be observed that the seven intervals, though nearly equal, do not exactly correspond: consequently, it is not possible to maintain the harmony of the notes, if any other than C be selected as the fundamental note. In order, therefore, that we may be enabled to select some other note than C, and at the same time, get rid of the inequalities subsisting between the seven intervals of the diatonic scale, *semitones* have been introduced

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186. Show that music is a natural language by some familiar illustrations.—*187. What is* the use of semitones? What is the chromatic *scale?*

between the *entire tones*, *i. e.* between the fundamental note and the second, between the second and the third, between the fourth and the fifth, between the fifth and the sixth, between the sixth and the seventh, and the octave is thus constituted of 8 entire tones, and 6 semitones. This scale, which contains 12 intervals, is called the *chromatic scale.* When the differences between the intervals are so far equalised, that the deviation from an exact ratio to the fundamental note is so small as to be imperceptible, an instrument, so tuned, is said to have an *even temperament.*

WIND, OR ATMOSPHERIC CURRENTS.

188. Wind is nothing more than air in motion, or an atmospheric current. As a natural phenomenon, that motion of the air which we call wind, is occasioned by the presence of a greater degree of heat in one place than in another: the air which has been heated, rises upward, while the surrounding portions move forward to occupy its place, and restore the equilibrium. The truth of this is illustrated by the fact, that during the burning of a house in a calm night, the motion of the air towards the place where it is thus rarefied, makes the wind blow from every point towards the flame. The *general currents* of the atmosphere depend principally upon two circumstances, viz. the unequal temperature of the equator and of the poles, and the diurnal motion of the earth upon its axis.

189. The effect of *temperature* in the production of atmospheric currents, is strikingly exemplified in islands situated in hot climates. "The land, during the daytime being under the rays of a tropical sun, becomes heated in a greater degree than the surrounding ocean, and consequently there rises from the land a stream of warm air during the day, while the cooler air from the surface of the water, moving forward to supply this partial vacancy, produces a cool breeze setting inland on all sides of the island. This constitutes the *sea-breeze*, which is so delightful to the inhabitants of those hot countries, and without which the inhabitants could hardly exist in some of the most luxuriant islands between the tropics.

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188. What is wind? As a natural phenomenon, how is wind produced, or, what is the cause of wind? How is this illustrated?—189, 190. In the islands of hot climates, why does the wind blow inland during the day, and *off* the land during the night? What are these breezes *called?*

190. "During the night the motion of the air is reversed, because the earth, being heated superficially, soon cools when the sun is absent, while the water, being warmed several feet below its surface, retains its heat longer. Consequently, towards morning, the earth becomes colder than the water, and the air sinking down upon it, seeks an equilibrium by flowing outwards, like rays from a centre, and thus the *land-breeze* is produced. The wind then continues to blow from the land until the equilibrium is restored, or until the morning sun makes the land of the same temperature as the water, when for a time there will be a dead calm. Then again the land becoming warmer than the water, the sea-breeze returns as before, and thus the inhabitants of those sultry climates are constantly refreshed during the summer season with alternate land and sea-breezes.

191. "At the equator, which is a part of the earth continually under the heat of a burning sun, the air is expanded, and ascends upwards, so as to produce currents from the north and south, which move forward to supply the place of the heated air as it rises. These two currents, coming from latitudes where the daily motion of the earth is less than at the equator, do not obtain its full rate of motion, and therefore, when they approach the equator, do not move so fast eastward as that portion of the earth, by the difference between the equator's velocity and that of the latitudes from which they come. This wind therefore falls behind the earth in her diurnal motion, and consequently has a relative motion towards the west. This constant breeze towards the west is called the *trade-wind*, because a large portion of the commerce of nations comes within its influence. While the air in the lower regions of the atmosphere is thus constantly flowing from the north and south towards the equator, and forming the trade-winds between the tropics, the heated air from these regions as perpetually rises, and forms a counter current through the higher regions towards the north and south from the tropics, thus restoring the equilibrium. These opposite motions are represented in the subjoined figure. Let A B C denote a portion of the earth's surface, A being in the

191. What is said of the ascent of heated air at the equator? What *is the consequence* on the air towards the north and south? How *are the trade winds formed?* While the air in the lower regions flows *from the north* and south towards the equator, in what direction does it *flow in the higher region*

direction of the north pole, C in that of the south pole, B representing the equator. The currents of the air pass in the direction of the arrows. The wind, therefore, from A to B, would blow, on the surface of the earth, from north to south, while from E to A the upper current would pass from south to north, until it reached A, when it would change its direction, and turn towards the south. The currents in the southern hemisphere, being regulated by similar laws, would assume similar directions.

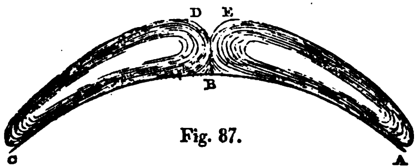

Fig. 87.

192. "This counter motion of the air in the upper and lower regions, is illustrated by a very simple experiment. Open a door a few inches, leading into a heated room, and hold a lighted candle at the top of the passage, the current of air, as indicated by the direction of the flame, will be *out* of the room. Then set the candle on the floor, and it will show that the current is there *into* the room. Thus, while the heated air rises and passes out of the room, that which is colder flows in, along the floor, to take its place. This explains the reason why our feet are apt to suffer with the cold, in a room moderately heated, while the other parts of the body are comfortable. It also explains why those who sit in the gallery of a church are sufficiently warm, while those who sit below may be shivering with cold. From such facts, showing the tendency of heated air to ascend, while that which is colder moves forward to supply its place, it is easy to account for the reason why the wind blows perpetually from the north and south towards the tropics; for the air being heated, as stated above, it ascends, and then flows north and south towards the poles, until, growing cold, it sinks down, and again flows towards the equator.

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192. How is this counter current in lower and upper regions illustrated by a simple experiment?

A DICTIONARY
OF
PHILOSOPHICAL TERMS.

ACCELERATION (*accelero*, to hasten). The augmentation or increase of motion in accelerated bodies.

ACOUSTICS (*akouo*, Gr. to hear) The science which treats of the nature, phenomena, and laws of the sense of sound. It extends to the theory of musical concord and harmony, and is, therefore, a valuable and interesting science.

AIR. A thin, elastic fluid, surrounding the globe of the earth. The air, together with the clouds and vapours that float in it, is called the atmosphere. The height to which the atmosphere extends, has never been ascertained; but at a greater height than forty-five miles, it ceases to reflect the rays of light from the sun.

AIR-PUMP. A machine made for exhausting the air from glass vessels, for the purpose of experiment in pneumatics.

ANGLE. The inclination of two lines meeting one another in a point, called the *vertex*. The lines are called the legs or sides of the angle. Angles, in geometry, are called *right*, *acute*, and *obtuse*. A right angle contains just 90 degrees, or the quarter part of a circle. Acute angles contain less, and obtuse angles more, than 90 degrees.

1. *Angle of incidence*. The angle contained between the line described by the incident ray, and a line perpendicular to the surface on which the ray strikes, raised from the point of incidence.

2. *Angle of reflection*. The angle contained between the line described by the reflected ray, and a line perpendicular to the reflecting surface, at the point from which the ray is reflected.

3. *Angle of refraction*. The angle contained between the line described by the refracted ray, and a line perpendicular to the refracting surface at the point in which the ray passes through that surface.

4. *Angle of vision*. The angle contained between lines coming from opposite parts of an object and meeting in the eye.

AQUEOUS HUMOUR. The watery humour of the eye. It is the first and outermost, and that which is less dense than either the vitreous or crystalline. It is transparent and colourless like water, and fills up the space that lies between the cornea and the crystalline humour.

ARÆOMETER (*araios*, thin, *metron*, measure). An instrument by which the density and gravity of fluids are measured.

ATMOSPHERE (*atmos*, vapour *sphaira*, a sphere). The fluid which surrounds our earth.

ATTRACTION. A general term, used to denote the power or principle by which bodies mutually tend towards each other, without regarding the cause or action that may be the means of producing the effect.

1. *Attraction of cohesion*. That kind of attraction which takes place between the constituent particles of the same body. By this principle bodies preserve their forms and are prevented from falling to pieces.

2. *Attraction of gravitation.* That form of attraction by which distant bodies tend towards one another.

AURORA BOREALIS or **NORTHERN LIGHTS.** A kind of meteor of a pale colour, sometimes seen in the northern parts of the heavens, supposed to be an electrical phenomenon.

AXIS. An imaginary line which passes through the centre of a body, and on which it turns.

AXIS OF MOTION. The line about which a revolving body moves. Philosophically speaking, the axis of motion is said to be at rest, whilst the other parts of a body move round it; and the further any part of a body is from the axis of motion, the greater is its velocity.

AXIS, IN OPTICS. That ray, among all others sent to the eye, which falls perpendicularly upon that organ, and which consequently passes through the centre of the eye.

AXIS OF A GLASS or **LENS.** A right line joining the middle points of the two opposite surfaces of the glass.

B

BALANCE. One of the simple mechanical powers, by which the equality or difference of weight in heavy bodies is discovered.

BALLOON. A machine used in navigation through the air. It takes its name from the form of the machine, the word *balloon* signifying any spherical hollow body, of whatever matter it be composed, or for whatever purposes it be designed.

BAROMETER (*bares*, weight, *metron*, a measure). An instrument for measuring the weight or pressure of the atmosphere; and by that means measuring heights and depths, determining variations in the state of the air, and foretelling the changes in the weather.

BASE. The lowest side of the perimeter of a geometrical figure. Thus, the base of a triangle may be said of any of its sides, but more properly of the lowest, or that which is parallel to the horizon. In rectangled triangles, the base is properly the side opposite to the right angle.

BASS, IN MUSIC. That part of a concert which consists of the gravest and deepest sounds, and which is played on the largest pipes or strings of the instrument.

BINOCLE, or **BINOCULAR TELESCOPE** (*bini oculi*, both eyes). A telescope by which the object can be viewed with both eyes at the same time.

BODY. A term applied in physics, to an extended solid substance, of itself utterly passive and inactive, indifferent either to motion or rest; but capable of any sort of motion, and of all figures and forms. Body, or substance, which is the same thing, is usually denoted by the general term matter.

BREADTH. One of the three dimensions of geometrical bodies, which, multiplied into their length, constitutes a surface.

BUBBLE. A small drop or vesicle of any fluid filled with air, and either formed on its surface, by an addition of more of the fluid, or in its substance, by an intestine motion of its component parts.

BURNING-GLASS. A convex or concave glass, commonly spherical, which, being exposed directly to the sun, collects all the rays falling thereon into a very small space, called the focus, where any combustible substance may be ignited.

C

CAMERA OBSCURA. Literally, a dark chamber. It is made by placing a convex glass in a hole of a window-shutter; and, if no light enters the room but through the glass, the pictures all objects on the outside may be tinctly seen in an inverted position, on any white surface placed at the focus of the lens.

CAPILLARY TUBES. Minute hair-like tubes, used for experiments in illustrating capillary attraction.

CENTRAL FORCES. The powers which cause a moving body to tend towards, or recede from, the centre of motion.

CENTRE OF GRAVITY. That point about which all the parts of a body, in any situation, balance each other.

CENTRE OF MOTION. That point which remains at rest, while all the other parts of a body move about it.

CENTRIFUGAL FORCE (*centrum*, the centre, *fugio*, to avoid). The force by which all bodies, that move round any other body in a curve, endeavour to fly off from the axis of their motion in a tangent.

CENTRIPETAL FORCE (*centrum*, the centre, *peto*, to seek). That force by which a body tends towards some point as a centre: such is gravity, or that force whereby bodies tend towards the centre of the earth; and that force, whatever it be, whereby the planets are continually drawn back from right-lined motions, and made to move in curves.

CHROMATICS (*chroma*, colour). That branch of optics which explains the several properties of the colours of light and of natural bodies.

CIRCLE. A plane figure comprehended by a single curved line, called its circumference, to which right lines or radii, drawn from a point in the centre, are equal to each other.

CIRCULAR VELOCITY. The velocity of a revolving body, measured by an arc of a circle.

CIRCUMFERENCE. The line or lines which bound a plane figure. The term is, however, generally applied in a more limited sense, to the curved line which bounds a circle, and otherwise called a periphery; the boundary of a right-lined figure being expressed by the term perimeter.

CLOUDS. A collection of misty vapours suspended in the air. Their various colours and appearances are owing to their particular situation in regard to the sun, to the different reflection of the sun's rays, and to the effects produced on them by wind.

COHESION (*cohæreo*, to stick together). A form of attraction by which the particles of a body cohere.

COLOUR. That property of bodies which affects the sight only; thus, the grass in the fields has a green colour, blood has a red colour, the sky generally appears blue.

COMPRESSION. The act of pressing or squeezing some matter, so as to bring its parts nearer to each other, and cause it to possess less space.

CONCAVE. A term applied to the inner surface of hollow bodies, more especially of spherical ones.

CONCORD. The relation of two sounds which are always agreeable to the ear, whether applied in succession or consonance.

CONDENSER. A pneumatic machine, whereby a considerable quantity of air may be forced into a given space.

CONDUCTORS. A term applied to long metallic rods, whose points are raised above buildings for the purpose of attracting or receiving the electric fluid, and of conducting it into the earth, or into water, thereby to prevent such buildings from being struck by lightning.

CONE. A solid geometrical figure, having a circle for its base, and its top terminated in a point or vertex.

CONVERGING LINES. Lines which continually approach nearer one another; or whose distance becomes still less and less.

CONVERGING RAYS. Those rays which, issuing from diverse points of an object, incline towards one another, till, at last, they meet and cross, and then become diverging rays.

CONVEX. An appellation given to the exterior surface of gibbous or globular bodies, in opposition to the hollow inner surface of such bodies, which is called concave. Thus we say a convex lens, a convex mirror, a convex superficies.

CORNEA (*cornu*, a horn). The second coat of the eye, so called from its substance, which resembles horn.

CRYSTALLINE HUMOUR. A thick compact humour, in form of a flattish convex lens, situated in the middle of the eye, serving to make that refraction of the rays of light, necessary to make them meet in the retina, and form an image thereon, whereby vision may be performed.

CYLINDER. A solid geometrical body, supposed to be generated by the rotation of a parallelogram.

D

DENSITY. The degree of closeness and compactness of the particles of a body; the property opposed to rarity.

DIAGONAL (*dia*, through, *gonia*, an angle). A right line drawn across a quadrilateral figure, from one angle to another; by some called the diameter of the figure.

DIAMETER (*dia*, through, *metron*, a measure). A right line passing through the centre of a circle, and terminated at each side by the circumference thereof.

DIMENSION. This term denotes either breadth, length, or thickness: hence a line has one dimension, *viz.* length; a superficies, two, *viz.* length and breadth; and a body, or solid, has three, *viz.* length, breadth, and thickness.

DIRECTION. The line or path of a body's motion, along which it endeavours to proceed, according to the force impressed upon it.

DISCORD. A dissonant and inharmonious combination of sounds, so called in opposition to concord.

DIVERGENT RAYS. Those rays, which, going from a point of the visible object, are dispersed, and continually depart one from another, in proportion as they are removed from the object; in which sense they are opposed to convergent rays.

DIVISIBILITY. That property by which the particles of matter in all bodies are capable of a separation or disunion from each other.

DROPS. Small spherical bodies, into which the particles of fluids spontaneously form themselves, when let fall from any height.

DUCT (*ductus*). A tube or canal.

DUCTILITY. A property of certain bodies, whereby they are capable of being expanded, or stretched forth by means of a hammer or press.

DYNAMICS (*dunamis*, Gr. power). This branch of mechanics relates to the action of forces that give motion to solid bodies; which forces are calculated, both by their active powers, and by the proportion of time in which those powers become efficient.

E

EARTHQUAKE. A sudden motion of the earth, occasioned, it is supposed, either by the discharge of some electrical power, or by large quantities of inflammable air, which, on being rarefied by internal fires, forces its way through the parts that surround it.

ECCENTRIC (*ex*, out, *kentron*, the centre). A term applied to circles and spheres which have not the same centre, and consequently are not parallel; in opposition to concentric, where they are parallel, having one common centre.

ECHO. A sound reverberated or reflected to the ear from some solid body.

ELASTICITY. That disposition in bodies by which they endeavour to restore themselves to the posture from whence they were displaced by an external force.

ELECTRICITY (*electron*, amber). An invisible, subtile fluid, which appears to pervade all nature, and, among other interesting phenomena, is the cause of thunder and lightning. Electricity is of two kinds—*positive* and *negative*. The positive is that state of a body which contains more than its due proportion; and the negative is that state of a body which contains less than its due proportion.

ELLIPSIS (*elleipo*, Gr. to leave out). A curved line returning into itself, and produced from the section of a cone by a plane cutting both its sides, but not parallel to the base.

EXHALATION. A general term for all the effluvia or steams raised from the surface of the earth in form of vapour. Some distinguish exhalations from vapours, expressing by the former all steams emitted from solid bodies, and by the latter, the steams raised from water and other fluids.

EXPANSION. The enlargement or increase of bulk in bodies, chiefly by means of heat.

EXPLOSION. A sudden and violent expansion of an aerial or other elastic fluid, by which it instantly throws off any obstacle that happens to be in the way, sometimes with incredible force, and in such a manner as to produce the most astonishing effects.

EXTENSION. One of the common and essential properties of body, or that by which it possesses or takes up some part of universal space, which is called the place of a body.

F

FIGURE. The surface or terminating extremities of any body; considered as a property of body affecting our senses, it is defined a quality which may be perceived by two of the outward senses. Thus a table is known to be square by the sight and by the touch.

FLUID. An appellation given to all bodies whose particles easily yield to the least partial pressure or force impressed.

FOCUS. A term applied in geometry and conic sections, to certain points in the parabola, ellipsis, and hyperbola, where the rays reflected from all parts of these curves concur and meet.

FOGS. Clouds which float on the surface of the earth, and clouds are fogs in the higher regions of the atmosphere; from many places these may be seen floating in the valleys, and often in the valleys they may be seen creeping along the sides of the mountains.

FORCE. The cause of the change in the state of a body, when, being at rest, it begins to move, or has a motion which is either not uniform or not direct. Mechanical forces may be reduced to two sorts, one of a body at rest, the other of a body in motion.

FORCING-PUMP. A kind of pump, in which there is a forcer or piston without a valve.

FOUNTAIN. A spring or source of water rising out of the earth.

FRICTION. The rubbing of the parts of engines and machines against each other, by which means a great part of their effect is destroyed.

FULCRUM. The prop or support by which a lever is sustained.

G

GRAVITY. A term used by physical writers to denote the cause by which all bodies move towards each other, unless prevented by some other force or obstacle.

H

HAIL. A compact mass of frozen water, consisting of such vapours as are united into drops, and are frozen while they are falling. They assume various figures, being sometimes round, at other times pyramidal, cuneated, angular, thin and flat, and sometimes stellated with six radii like the small crystals of snow.

HALO. A meteor in the form of a luminous ring or circle, of various colours, appearing round the bodies of the sun, moon, or stars.

HARDNESS. The resistance opposed by a body to the separation of its particles. This property depends on the force of cohesion; and a body is considered more hard in proportion as it presents a greater resistance to the force which may be applied in order to separate its parts.

HARMONY. The agreeable result, or union, of several musical sounds, heard at one and the same time, or the mixture of divers sounds, which together have an effect agreeable to the ear. As a continued succession of musical sounds produces melody, so does a continued combination of these produce harmony.

HARMONY OF THE SPHERES. A sort of music much talked of by many of the ancient philosophers, supposed to be produced by the sweetly-tuned motions of the stars and planets. This harmony they attributed to the various proportionate impressions of the heavenly globes upon one another, acting at proper intervals.

HEIGHT. A perpendicular let fall from the vertex, or top, of any right-lined figure, upon the base or side subtending it. It is likewise the perpendicular height of any object above the horizon.

HURRICANES. Violent storms, frequent in South America and the West Indies, and other hot countries, in which the wind changes in a short time to every point of the compass, and blows with a violence which scarcely any thing can resist.

HYDRAULICS (*hydor*, water, *aulos*, a pipe). The science which investigates the velocity and impetus of fluids when in motion, and serves as the basis for computing the powers of various machinery acted upon by running water.

HYDROMETER (*hydor*, water, *metron*, a measure). An instrument to measure the extent and specific gravity of fluids.

HYDROSTATICAL BALANCE. A kind of balance contrived for the easy and exact finding of the specific gravities of bodies both liquid and solid.

HYDROSTATICAL PARADOX. A term denoting that any quantity of fluid, however small, may be made to balance or counterpoise any quantity, however large.

HYDROSTATICS (*hydor*, water, *statikos*, standing). The science which treats of the nature, gravity, and pressure of fluids in general, and of the methods of weighing solids in them.

I

IMAGE. The appearance of an object made either by reflection or refraction. In all plane mirrors, the image is of the same magnitude as the object, and it appears as far behind the mirror as the object is before it. In concave mirrors the image appears larger, and in those which are convex it appears less, than the object.

IMPENETRABILITY. That property of a body whereby it cannot be pierced by another; thus, a body which so fills a space as to exclude all others, is said to be impenetrable.

INCIDENCE (*incido*, to fall upon). The direction in which one body strikes on another.

INCLINATION. A word frequently used by mathematicians, to denote the mutual approach, tendency, or leaning of two lines, or planes, toward each other, so as to make an angle.

INCLINED PLANE. A line or plane which makes an angle with the horizon. It is frequently used to move weights from one level to another.

INERTIA (*iners*, inactive). That property of matter by which it would always continue in the same state of rest, or of motion in which it was put, unless changed by some external force.

INTEGRAL. An appellation given to parts of bodies which are of a similar nature with the whole. Thus, filings of iron have the same nature and properties as bars of iron.

INTENSITY. The degree or rate of power or energy of any quality, as of heat and cold.

L

LENS. A piece of glass or other transparent substance, which either collects the rays of light into a point, in their passage through it, or disperses them further apart, according to the laws of refraction; it is generally applied to an optic glass.

LEVEL. An instrument constructed for the purpose of ascertaining the exact level of any fluid, building, or any other object. Levels are of two kinds—the horizontal and the perpendicular.

LEVER. An inflexible right line, rod, or beam, supported in a single point on a fulcrum or prop, and used for the raising of weights; being either void of weight itself, or at least having such a weight as may be commodiously counterbalanced.

LIGHT. The agent by which objects are made perceptible to our sense of seeing: or the sensation occasioned in the mind by the view of luminous objects.

LIGHTNING. An electrical explosion.

LINE. A geometrical quantity extended in length only, without any breadth or thickness.

LIQUID. A fluid not sensibly elastic, the parts of which move on each other, and yield to the smallest impression.

LOOKING-GLASSES. Plain mirrors of glass, which, being impervious to the light, reflect the images of things placed before them.

M

MAGIC LANTERN. An instrument used for magnifying paintings on glass, and throwing their images upon a white screen in a darkened room.

MAGNETISM. The science which explains the properties of the loadstone, or natural magnet, which is a dark-coloured and hard mineral body, and is found to be an ore of iron, being generally found in iron mines.

MAGNITUDE. Whatever is made up of parts locally extended, or that has several dimensions; as, a line, a surface, or a solid.

MANOMETER (*manos*, Gr. rare, *metron*, a measure). An instrument for showing or measuring the alterations in the rarity or density of the air.

MATHEMATICS (*manthano*, to learn). Originally any discipline or learning; but at present the term denotes that science which teaches or contemplates whatever is capable of being numbered or measured, in so far as it is computable or measurable; and accordingly is subdivided into arithmetic, which has numbers for its object, and geometry, which treats of magnitudes.

MATTER. The general name of every substance, which has length, breadth, and thickness.

MECHANICS (*mechanè*, Gr. a machine). The science which treats of the laws of the equilibrium and motion of solid bodies; of the forces by which bodies, whether animate or inanimate, may be made to act upon one another; and of the means by which these may be increased, so as to overcome such as are most powerful.

MEDIUM. That space or region through which a body in motion passes to any point; thus ether is supposed to be the medium through which the heavenly bodies move; air, the medium wherein bodies move near the earth; water, the medium wherein fishes live and move; and glass is also a medium of light, as it affords it a free passage.

MELODY. The agreeable effect of different sounds ranged and disposed in succession; so that melody is the effect of a single voice or instrument, by which it is distinguished from harmony.

METEOR. A moveable igneous body, collected in the air by means not thoroughly understood, and varying greatly in size and rapidity of motion.

METEOROLOGY. The science of studying the phenomena of the atmosphere; and that term by which are expressed all the observations that tend to make them a system.

MICROMETER (*mikros*, small, *metron*, a measure). An instrument fitted to a telescope, for the purpose of measuring small angles, such as the diameters of the celestial bodies.

MICROSCOPE. An instrument by means of which small objects are made to appear larger than they do to the naked eye.

MINUTE. The sixtieth part of a degree of a circle. Minutes are denoted by one acute accent, thus (′); the second, or sixtieth part of a minute, is by two such accents, thus, (″); and the third by three (‴).

MIRROR. Any polished body which is impervious to the rays of light, and reflects them equally. Mirrors were anciently made of metal; but at present they are generally smooth plates of glass, tinned or quick-silvered on the back part, and called looking-glasses. The doctrine of mirrors depends wholly on that fundamental law, that the angle of reflection is always equal to the angle of incidence.

MOBILITY. That property of matter by which it is capable of being moved from one part of space to another.

MOMENTUM. A term, signifying the same as impetus, or quantity of motion in a moving body; this is always equal to the quantity of matter multiplied into the velocity; or, which is the same thing, it may be considered as a rectangle under the quantity of matter and velocity.

MONSOONS. Periodical winds, frequent in the Eastern and Southern oceans, which for six months blow constantly the same way, and the contrary way the other six months. These are otherwise called *trade-winds*.

MOTION. The continued and successive change of place. Nothing can be produced or destroyed without motion, and every thing that happens depends on it.

MUSIC. Any succession of sounds, however much they may vary in regard to duration, or however much they may partake of various modes or keys, provided that the succession be agreeable, and excite, in a well-tuned ear, certain agreeable sensations, is called music.

N

NATURAL PHILOSOPHY. That science, otherwise called physics, which considers the powers of nature, the properties of natural bodies, and their actions upon one another.

O

OBLATE. Flattened, or shortened, as an oblate spheroid, having its axis shorter than its middle diameter, being formed by the rotation of an ellipse about the shorter axis. The oblate-ness of the earth refers to the diminution of the polar axis in respect of the equatorial.

OBTUSE. Blunt, or dull, in opposition to sharp or acute. Thus we say an angle is obtuse, if it measures more than ninety degrees.

OPACITY. A quality of bodies which renders them impervious to the rays of light.

OSCILLATION. The vibration or reciprocal ascent and descent of a pendulum.

P

PARABOLA (*parabole*, Gr. juxtaposition). A geometrical figure arising from the section of a cone, when cut by a plane parallel to one of its sides.

PARADOX (*para*, beside, *doxa*, opinion). A proposition seemingly obscure, as being contrary to some received opinion, but yet true in fact.

PARALLEL. Those straight lines, whose least distances from each other are every where equal, are said to be parallel.

PARALLELOGRAM. A quadrilateral right-lined figure, whose opposite sides are parallel and equal to each other.

PARHELION (*para*, beside, *helios*, the sun). A mock sun, or meteor, in form of a very bright light, appearing on one side of the sun.

PENDULUM. Any heavy body so suspended that it may vibrate or swing backwards and forwards, about some fixed point, by the force of gravity. The vibrations of the pendulum are called its oscillations.

PERCUSSION. The impression a body makes in falling or striking upon another, or the shock of two bodies in motion.

PERIMETER (*peri*, around, *metron*, a measure). The bounds or limits of any figure or body. The perimeter of surfaces or figures are lines, those of bodies are surfaces. In circular figures, instead of perimeter, we say circumference, or periphery.

PERIPHERY (*peri*, around, *phero*, to carry). The circumference of a circle, ellipsis, or any other regular curvilinear figure.

PERPENDICULAR. A line, falling directly on another line, so as to make equal angles on each side; called also a normal line.

PERSPECTIVE. The art of representing, upon a plane surface, the appearance of objects, however diversified, similar to what they assume upon a glass-pane, interposed between them and the eye at a given distance.

PHYSICS (*physis*, Gr. nature). A term employed in natural philosophy for explaining the doctrines of natural bodies, their phenomena, causes, and effects, with their various affections, motions, and operations.

PISTON. A short cylinder of metal, or other solid substance, fitted exactly to the cavity of the barrel or body of the pump. There are two kinds of pistons used in pumps, the one with a valve, and the other without a valve, called a forcer.

PLANE. A plain surface, or one that lies evenly between its bounding lines—and as a right line is the shortest extension from one point to another, so a plain surface is the shortest extension from one line to another.

PNEUMATICS (*pneuma*, wind). That branch of natural philosophy which treats of the weight, pressure, and elasticity of the air, with the effects arising from them.

POINT. This term, in geometry, as defined by Euclid, is a quantity which has no parts, or which is indivisible. Points are the ends or extremities of lines. If a point be supposed to be moved any way, it will, by its motion, describe a line.—Point, in physics, is the least sensible object of sight, marked with a pen, point of a compass, or the like. Of such points all physical magnitude consists.

POLARITY. The quality of a thing considered as having poles; but chiefly used in speaking of the magnet.

POWER. This term, in mechanics, denotes any force, whether of a man, a horse, a spring, the wind, or water, which, being applied to a machine, tends to produce motion.

PROJECTION. The art of communicating motion to a body, thence called projectile.

PULLEY. One of the mechanical powers, called by seamen a tackle.

PUMP. A machine formed on the model of a syringe, for raising water.

PYROMETER (*pur*, fire, *metron*, a measure). An instrument for measuring the expansion of bodies by heat.

Q

QUADRATURE. A geometrical term, denoting the squaring or reducing a figure to a square. That position of the moon, when she is 90 degrees from the sun.

QUADRILATERAL. A geometrical figure whose perimeter consists of four right lines making four angles, whence it is also called a quadrilateral figure. The quadrilateral figures are either a parallelogram, trapezium, rectangle, square, rhombus, or rhomboid.

R

RADIANT POINTS. Those points from whence rays of light flow in all directions.

RADIATION. The act of a body emitting or diffusing rays of light all around, as from a centre.

RADIUS. The semi-diameter of a circle, or a right line drawn from the centre to the circumference.

RAIN. Whatever suddenly disturbs the heat or density of the air, or the *electricity* of the clouds, occasions the particles of vapour to rush together, and form drops of water too heavy to continue suspended in the atmosphere. They then fall in the shape of rain, and increase in size as they fall by combining with the floating vapours as they pass through them.

RAINBOW. A meteor in form of a party-coloured arch, or semicircle, exhibited only at the time when it rains. It is always seen in that point of the heavens which is opposite to the sun, and is occasioned by the refraction and reflection of his rays in the drops of falling rain.

RAREFACTION. The making a body to expand, or occupy more room or space, without the accession of new matter.

RAY. A beam of light, emitted from a radiant or luminous body.

REACTION. The resistance made by all bodies to the action or impulse of others which endeavour to change its state, whether of motion or rest.

RECEIVER. A glass vessel employed in pneumatical experiments for containing the object on which an experiment in the air-pump is to be made.

RECTANGLE. A geometrical term denoting a right-angled parallelogram.

REFRACTION (*refrango*, to break back). The deviation of a moving body from its direct course, occasioned by the different density of the medium in which it moves; or it is a change of direction, occasioned by a body's falling obliquely out of one medium into another of a different density. Refraction causes the heavenly bodies to appear more elevated above the horizon than they really are.

REPULSION. That property in bodies, whereby, if they are placed just beyond the sphere of each other's attraction of cohesion, they mutually fly from each other

RESISTANCE. In general an

power which acts in an opposite direction to another, so as to destroy or diminish its effects.

RETINA. The expansion of the optic nerve on the internal surface of the eye, whereupon the images of objects being painted, are impressed, and by that means conveyed to the common sensory in the brain, where the mind views and contemplates their ideas.

ROTATION (*rota*, a wheel). A term chiefly applied to the circumvolution of any surface round a fixed and immoveable line, which is called the axis of its rotation, and by such rotations it is that solids are conceived to be generated.

S

SEGMENT OF A CIRCLE. That part of the circle contained between a chord and an arc of the same circle.

SEMICIRCLE. Half a circle, or that figure comprehended between the diameter of a circle and half the circumference.

SEMIDIAMETER. Half the diameter, or a right line drawn from the centre of a circle, or sphere, to its circumference; otherwise called the radius.

SEXTANT. The sixth part of a circle, or an arc comprehending sixty degrees. The word sextant is more particularly applied to an astronomical instrument made like a quadrant, excepting that its limb comprehends only sixty degrees. The use and application of the sextant is the same with that of the quadrant.

SIPHON. A bended pipe, one end of which being put into a vessel of liquor, and the other hanging out of the said vessel over another, the liquor will run out from the first into the last, after the air has been sucked out of the external or lower end of the siphon, and that as long as the liquor in the upper vessel is above the upper orifice of the siphon.

SNOW. A well known substance, formed by the freezing of the vapours in the atmosphere. It differs from hail and hoar-frost, in being, as it were, crystallized, which they are not.

SOLID. A term applied to a body whose parts are so firmly connected together, as not to give way, or slip from each other, upon the smallest impression; in which sense solid is opposed to fluid.

SOUND. The sense of hearing is effected by the pulsations or vibrations of the air, which are caused by its own expansion, or by the vibrations of sounding bodies. These sensations, or vibrations in the air, are called sounds, as are also the sensations which they produce.

SPECIFIC. That which is peculiar to any thing, and distinguishes it from all others.

SPECTRUM. A term applied in optics. When a ray of light is admitted through a small hole, and received on a white surface, it forms a luminous spot. If a dense, transparent body be interposed, the light will be refracted, in proportion to the density of the medium; but if a triangular glass prism be interposed, the light is not merely refracted, but it is divided into seven different rays. This image is called the spectrum, and, from its being produced by the prism, it is termed the prismatic spectrum.

SPHERE. A solid contained under one uniform round surface, such as would be formed by the revolution of a circle about the diameter thereof, as an axis.

SPRAY. The sprinkling or foam of the sea, which is driven from the top of a wave in stormy weather.

SQUARE. A quadrilateral figure, both equilateral and equiangular.

SUCTION. The act of sucking or drawing up a fluid, as air, water, milk, or the like, by means of the mouth and lungs.

SUPERFICIES, or SURFACE. A magnitude considered as having two dimensions; or extended in length and breadth, but without thickness or depth.

SYRINGE. An instrument serving to imbibe or suck in a quantity of any fluid, and to squirt or expel the same with violence.

T

TANGENT. A straight line touching the circumference of a circle in one point; or a right line, which touches any arc of a curve, in such a manner as to make a right angle with the diameter of the circle of which that arc is a part.

TANTALUS'S CUP. A philosophical toy for exhibiting the principle of the siphon.

TELESCOPE (*tele*, afar off, *skopeo*, to look). An optical instrument, used for discovering and viewing distant objects, either directly by glasses, or by reflection.

THERMOMETER (*therme*, heat, *metron*, a measure). An instrument showing the degrees of heat and cold. It is used conjointly with the barometer, for correcting the variation in the refraction, from the change of temperature and specific gravity of the atmosphere.

THUNDER. The noise occasioned by the explosion of a flash of lightning passing through the air: or it is that noise which is excited by a sudden explosion of electrical clouds, which are therefore called thunder-clouds.

TRADE-WINDS. Certain regular winds at sea, blowing either constantly the same way, or else alternately, a certain length of time in one direction, and then as long in an opposite one. They are called trade-winds from their use in navigation, and are very common in the Indian seas.

TRANSMISSION. The act of a transparent body passing the rays of light through its substance, or suffering them to pass; in which sense the word is opposed to reflection.

TRANSPARENCY. A quality of certain bodies, whereby they give passage to the rays of light, in contradistinction to opacity, or that quality of bodies which renders them impervious to the rays of light.

TRIANGLE. A geometrical figure of three sides and three angles.

U

UNDULATION (*undula*, a little wave). A kind of tremulous motion or vibration observable in a fluid, whereby it alternately rises and falls like the waves of the sea.

UNISON. The effect of two sounds which are equal in degree of tune, or in point of gravity and acuteness.

V

VACUUM. A space empty or devoid of all matter or body.

VALVE. A kind of lid or cover of a tube or vessel, so contrived as to open one way, but which the more forcibly it is pressed the other way, the closer it shuts the aperture, so that it either admits the entrance of a fluid into the tube or vessel and prevents its return, or admits its escape and prevents its re-entrance.

VAPOUR. A thin, humid matter, which being rarefied to a certain degree by the action of heat, ascends to a particular height in the atmosphere, where it is suspended, until it returns in the form of dew, rain, snow, or hail.

VELOCITY. Swiftness, or that affection of motion, whereby a moving body is disposed to run over a certain space in a certain time.

VIBRATION. A regular reciprocal motion of a body, as for example, of a pendulum which, being freely suspended, swings or vibrates from side to side.

VISIBLE. Something that is an object of sight or vision, or something whereby the eye is affected, so as to produce a sensation.

VISION. The act of seeing or of perceiving external objects by the organ of sight.

VOLCANOES. Mountains which emit ignited matter and smoke through apertures, communicating with cavities in the depths of the earth.

W

WATER. A transparent fluid, without colour, smell, or taste; in a very small degree compressible; and, when pure, not liable to spontaneous change.

WATER-SPOUT. An extraordinary meteor, in which a column of water is seen hanging from the clouds, and descending until it meets with a column rising from the ocean. They unite and often move with rapidity, until they meet with some opposing wind, or other cause, which destroys them.

WAVE. A volume of water elevated by the action of the wind, upon its surface, into a state of fluctuation, and accompanied by a cavity.

WEDGE. One of the mechanical powers, as they are called. The wedge is a triangular prism, whose bases are equilateral acute-angled triangles.

WEIGHT. A quality in natural bodies, by which they tend towards the centre of the earth.

WHEEL. One of the six powers of mechanism; which, without doubt, contributes more than any of the other five to the general convenience of mankind, by the wonderful variety of purposes, from a mill to a watch, wherein it is employed.

WHIRLWINDS. These are formed by opposite winds meeting and moving swiftly in a circle, raising sand and light bodies into the air. In the deserts of Africa they sometimes draw np the sand into a moving pillar, which buries all in its way. When they appear on the ocean, they draw up the water, and produce *water-spouts*.

WIND. When the air over any place is more heated than that around, it is rarefied or expanded, and rises. The surrounding air rushes in to supply its place, and this produces a current called wind.

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The above First Books of Astronomy and of Natural Philosophy are believed be not unfavourable specimens of Treatises of the character referred to. Th are therefore presented by the Publisher as the first of a series of elementa Text Books, intended to be published by him, on those branches of science which is presumed might be advantageously introduced in schools, as preparatory to a mo finished education, and for students intended for the learned professions. The First Books will also be adapted for those desirous of attaining the elements science in a systematic manner, without the assistance of teachers, at as little e pense of time and money as the subjects will admit. For these purposes, they w e written in easily intelligible language, yet so as not to sacrifice truth to ornamen r to substitute sentimentalism for science; the object kept in view being to con uch knowledge of the several subjects as will suffice for elementary instruc nable those desirous of extending their information to pursue their futu s with advant